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Secondary tillage tool effect on soil aggregation

Kamal Mohamed Adam
Iowa State University

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by

Kamal Mohamed Adam

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SYMBOLS AND ABBREVIATIONS

AD	After disking
AF	After field cultivating
AMS	Aggregate mechanical stability
AT	After tillage
BD	Before disking
BF	Before field cultivating
BT	Before tillage
C	Celsius
cm	Centimeter
D	Disking
db	Moisture content on dry basis
DOU	Samples dropped or undropped
Eng.	Crushing energy in Joules
FC	Field cultivating
g/cm^3	Grams per cubic centimeter
IMP	Implement
km/h	Kilometers per hour
kg	Kilograms
m	Meter
Max.F	Maximum force in Newton
MC	Moisture content
MWD	Mean-weight-diameter
PL	Plastic limit
Rep	Replication
Rev/min	Revolutions per minute

State Refers to before tillage or after tillage

x_i Refers to diameter of any particular size range of aggregates separated by sieving

w_i Weight of aggregates in size range as a fraction of the total weight of the sample analyzed

Σ Summation sign

CHAPTER I. INTRODUCTION

Soil tillage can be defined as a sequence of mechanical manipulations of the topsoil which are adapted to overall production technology (Krause et al., 1984). In addition to use in controlling weeds and managing crop residue, tillage plays an important role in changing soil structure. Soil structure is changed to create conditions favoring the germination of seeds, emergence of seedlings and growth of cultivated plants.

Tillage for seedbed preparation, herbicide incorporation and row crop cultivation may be structurally damaging to the soil. This damage may manifest itself as surface crust, large clods in seedbed, poor germination of seeds, and delayed emergence of seedlings (Hamblin, 1987). Structural damage is accelerated and may become critical when soils are worked while near their plastic limit (Utomo and Dexter, 1981). Therefore practices associated with preparation of the seedbed are of supreme importance because they give a chance to create a desirable structure that allows optimum crop production (Raney and Zingg, 1957) and maintains the aggregate strength that makes soil less susceptible to erosion caused by particle detachment due to raindrop impact (Francis and Cruse, 1983).

It is generally accepted that an aggregate size range of 1 to 5 mm is required for a good seedbed (Russell, 1961). Dexter (1988) defined good soil structure as "the spatial heterogeneity of different components or properties of soil". He also stressed the importance of soil structure for plant development, soil water balance and soil workability. The soil structure produced depends on many factors but the most important factor, at the time of tillage, that influences aggregate structure and surface condition, is soil moisture content (Lyles and Woodruff, 1962; Ojeniyi and

Dexter, 1979). However, the optimum moisture content at the time of tillage that will give good soil structure in the seedbed is not known.

CHAPTER II. LITERATURE REVIEW

The effects of soil moisture content at the time of tillage on the structure formed has been investigated by several workers. Baver (1957) concluded that tilling the soil between the two water content extremes of field capacity and permanent wilting point results in formation of finely pulverized soil made up of smaller clods. Lyles and Woodruff (1962) investigated the effect of moisture content at time of tillage on cloddiness for wind erosion control on silty clay loam soil. The mechanical composition of the soil used was: sand 19.5 %, silt 49.1 %, and clay 31.4 %. The lower plastic limit was 21.6 % w/w. They concluded that soil moisture at time of tillage has a definite effect on the size distribution of aggregates produced. Fewer large aggregates were found at intermediate soil moisture levels (15 to 23 percent on oven-dry basis) for the soil used in their study. They studied the strength of aggregates formed at different soil moisture contents. They tilled the soil at five levels of gravimetric moisture content ranging from 8 to 25 percent. They used a standard 5-ft one-way disk, a 5-ft V-type subsurface sweep, and a 14-inch two-bottom moldboard plow. They concluded that aggregates formed at low moisture content have three to four times more resistance to crushing than those formed at higher moisture levels (greater than 16 percent). They concluded that resistance to crushing may decrease with drying if the soil is tilled at low moisture content. Dan (1963) conducted an experiment to investigate the influence of certain tillage implements and operations on aggregate size distribution and other soil physical properties. He used a moldboard plow, disc harrow and a spike tooth harrow in five tillage treatments. The tillage treatments studied were plowing,

plowing plus one disking, plowing plus one disking and one harrowing, plowing plus two diskings, and plowing plus three diskings. He conducted seven separate experiments on three different soil types. One experiment on Nicollet-Webster soil, four on Colo silt loam soil and two on Glenco-Webster soil. In four of the soils he noted a trend related to moisture content when tillage was performed. He concluded that the mean weight diameter of soil aggregates was less when soil was drier when tilled. Harris et al. (1966) reported that the effect of tillage on aggregation is a function of soil moisture content at time of tillage and that cultivation improves aggregation when the soil moisture content lies within a certain range and when the soil is worked with a suitable implement. Ojeniyi and Dexter (1979) conducted an experiment on Urrbrae red brown soil which is composed of 17 % clay, 32 % silt and 51 % sand. The lower plastic limit, PL, of this soil is at 19.5 % water content. The objective of their study was to determine the effect of soil moisture content at time of tillage on properties of aggregates produced. They found that tillage performed at a gravimetric water content of 17.0 percent produced the smallest percentage of large aggregates. They also found that tillage at 15.8 percent water content resulted in 57 percent of aggregates being larger than 4.0 mm in diameter, whereas tillage at 18.3 percent water content resulted in 66 percent of aggregates larger than 4.0 mm in diameter. They used a set of tines arranged in four rows, with tines in each row spaced at 30-cm intervals. The width of each tine point was 6.5 cm.

CHAPTER III. OBJECTIVES

The objectives of this work are:

1. To determine the effect of soil moisture content at the time of tillage on the change of soil aggregate size distribution caused by tillage.
2. To evaluate the mechanical stability of aggregates formed by tillage at different levels of soil moisture content at time of tillage.
3. To determine the maximum force and the energy required to crush the soil aggregates as a function of soil moisture content at time of tillage.
4. To evaluate the effect of type of tool used for tillage on soil aggregation and soil aggregate properties.

CHAPTER IV. MATERIAL AND METHODS

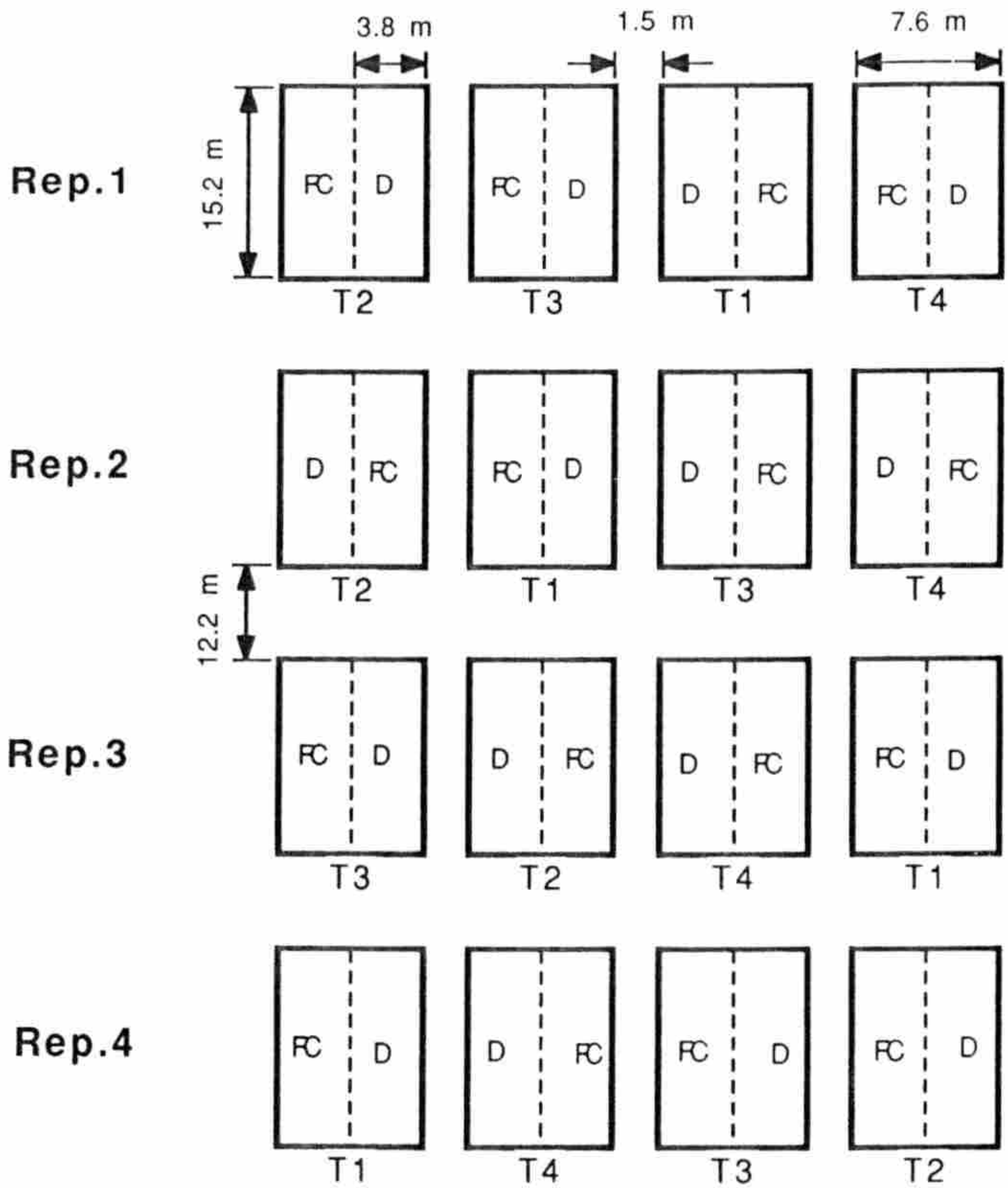
Experimental Design

Tillage treatments were evaluated in a field experiment on a fine-loamy mixed mesic aquic hapludolls (Nicollet) soil at the Agricultural Engineering Research Center near Ames, Iowa. Table 1 shows the mechanical analysis of the soil. The mechanical analysis was done by the pipette method. The clay type was 2:1 expanding montmorillonite. Corn was grown in the field the year before the research but destroyed by mowing when it was 36 in high and the residue was left on the surface. Corn was also grown the year of the study. The cultural practices to establish the corn crop were disking, field cultivating, rotary hoeing and two sweep cultivations. The lower plastic limit, PL, of the soil is 19.7 percent water content on dry basis. Lower plastic limit was determined according to the standard procedure of the American Association of State Highway and Transportation Officials (1978).

Table 1. Mechanical analysis, pH and organic matter content of the experimental soil

Sand 2 - 0.05 mm	Coarse silt 50 - 20 μ	Fine silt 20 - 2 μ	Clay < 2 μ	pH	Organic matter
----------	---------- %	----------	----------		%
38.3	19.4	19.5	22.8	4.88	3.64

A split-plot, randomized complete block design was used. Figure 1 shows the field layout used. Main plots were moisture content at time of tillage. Tillage was done at four levels of gravimetric soil moisture



Main treatments

Soil moisture content

	0 - 5 cm depth	5 - 10 cm depth
T1 =	12.8 %	14.9 %
T2 =	13.2 %	-
T3 =	15.5 %	16.0 %
T4 =	21.0 %	22.3 %

Sub treatments

Implements

D = Disk

FC = Field cultivator

Figure 1. The layout of the field of the experimental site

content varying from 12.8 to 21.0 percent. Each main plot was 7.6 x 15.2 m. Tillage implements, a 3.66-m tandem disk harrow (Figure 2) and a 3.8-meter field cultivator with sweep type blades (Figure 3), were assigned to subplots, 3.8 x 15.2 m in size (see Appendix B for tillage tool details).

Test Procedure

Different soil moisture contents were achieved by tilling on dates when rainfall and evaporation had produced the appropriate conditions. Samples for moisture content and bulk density were taken prior to tillage. Samples for aggregate analysis were taken both before and after tillage. Tillage speed and working depth were about 7.2 km/h and 10 cm, respectively, for both implements. Tillage depth was set by adjusting implement gauge wheels with machines on a flat concrete surface. Soil samples for moisture content determination were taken with a 2.5-cm diameter hand-operated soil sampling tube. Samples were taken from 5 locations on each plot. They were obtained from 0 - 5 and 5 - 10 cm depth for each tillage time except the first when samples were taken at 0 - 5 cm surface layer only.

Soil bulk densities were determined to give additional information about the soil of the experimental site. They were taken with Uhland core sampler (Figure 4). They were obtained from the 0 - 7.5 cm soil layer. Bulk densities were determined on dry basis.

Prior to tillage, soil samples for aggregate analysis were taken with a flat spade (Keen, 1931; Armbrust et al., 1982) to the depth of 10 cm. Five samples were taken at random points from each plot, placed in plastic containers, and transported to laboratory to air dry.

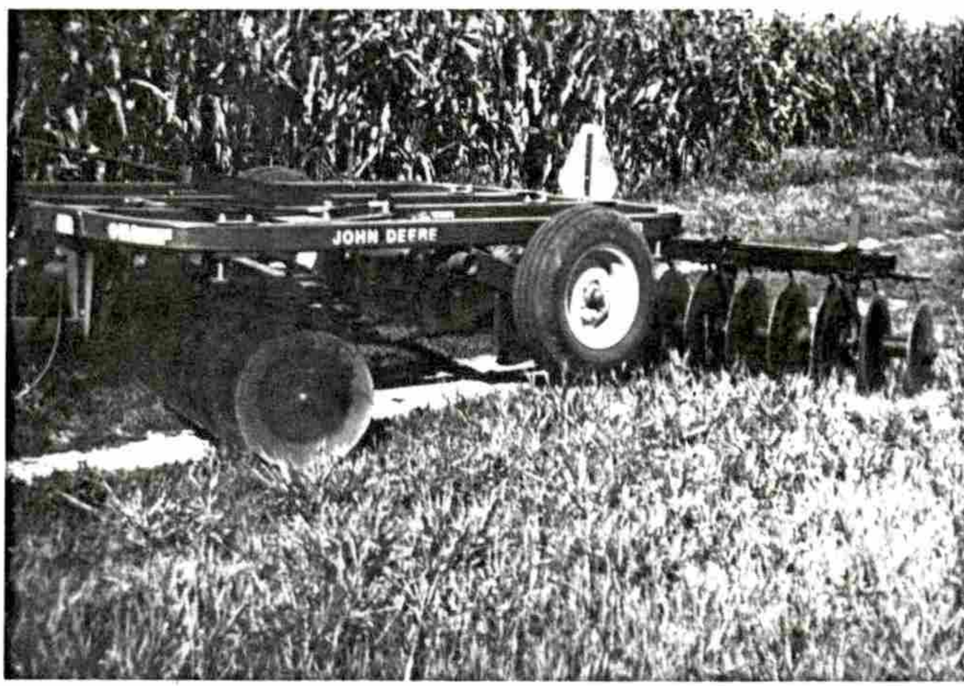


Figure 2. Disk harrow used for tillage treatment

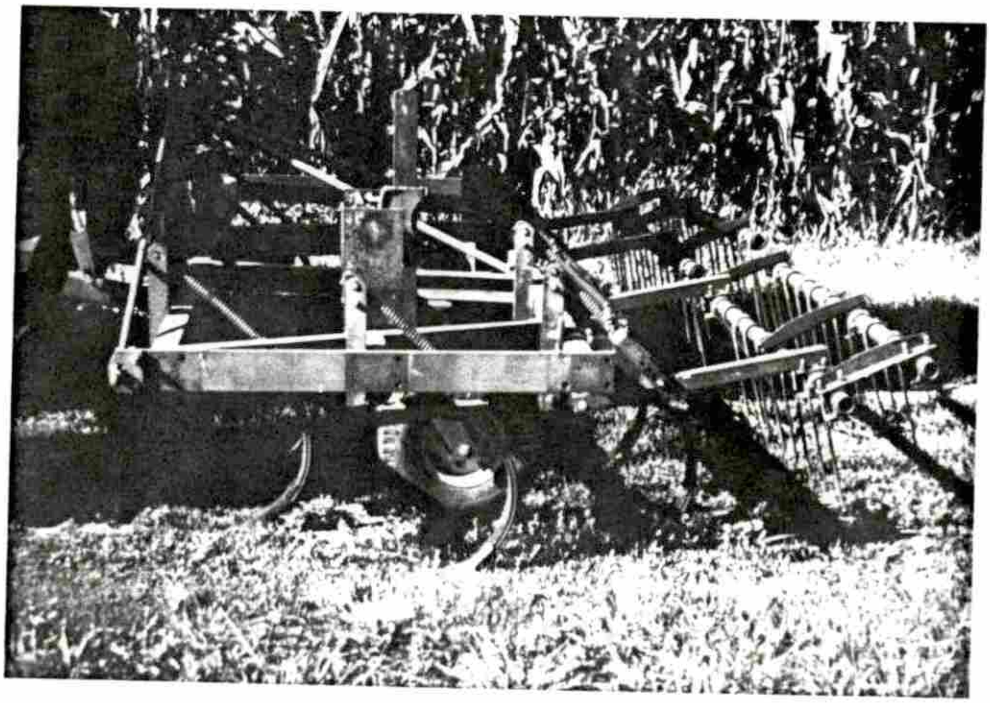


Figure 3. Field cultivator used for tillage treatment

Tillage was done with a tandem disk harrow and a C-Shank sweep type field cultivator immediately after the samples for moisture content, bulk density and the pre-tillage aggregate size were taken.

Immediately following tillage, soil samples for aggregate analysis were taken as above to the depth of tillage. Wheel tracks were avoided because the strength and the aggregate diameter of wheel tracked clods were greater than that of nonwheel tracked clods (Voorhees et al., 1978).

After the soil samples were air dried (to moisture content 5 % w/w), each sample was split. One half was sieved with a rotary sieve (Figure 5) Chepil (1962). The soil in each size range was weighed. The mean weight diameter was computed for each sample and was used as an index to express aggregate size (Van Bavel, 1949; Youker and McGuinness, 1956). The mean weight diameter was based on weighing the mass of aggregates of the various size classes according to their respective size. It was determined from the following equation:

$$MWD = \Sigma \, x_i \, w_i \qquad (1)$$

where MWD is the mean weight diameter, x_i is the mean diameter of any particular size range of aggregates separated by sieving, and w_i is the weight of the aggregates in that size range as a fraction of the total dry weight of the sample analyzed. The summation accounts for all size ranges, including the group of aggregates smaller than the opening of the finest sieve. The other half was subjected to a drop shatter test using a soil dropper (Figures 6 and 7). The drop-shatter test has been described by Marshall and Quirk (1950), Ingles (1963), and Hadas (1984). Basically this test measures soil break-up as a function of impact energy. The soil dropper was built to drop the soil samples from a known height onto a solid metal sheet that tilted at an angle of 30 degrees to the horizontal. After impact the soil flowed to a collection pan. This procedure avoided having aggregates fall on previously dropped soil. The dropped samples were then sieved with the rotary sieve. Aggregate stability was calculated as the difference in mean weight diameter of the soil before and after dropping.

Aggregates of 12.7-mm (0.5 in) to 25-mm (1 in) and 6.35-mm (0.25 in) and 12.7-mm (0.5 in) size fractions from each treatment combination were crushed (Rogowski, 1964). The moisture content of the aggregates at crushing was about 3.0 % on dry basis. Soil aggregates were crushed by loading them between parallel plates (Skidmore and Powers, 1982; Boyd et al., 1983).

The crushing was done on an Instron Model 8501, Universal Testing Instrument (Figure 8). Randomly selected individual aggregates were placed on a platform supported by a load cell of Model 1010 - AF, with a load capacity of 5000 pounds (22241 N). A hydraulically operated anvil was used to compress the aggregate against the load cell with a speed of 278 mm/sec., until the aggregate was crushed. The crushing energy for each aggregate was determined by integrating the area under the force-displacement curve. This energy was calculated by a numeric integration program written in Basic. The maximum force for each aggregate was also determined with this program.

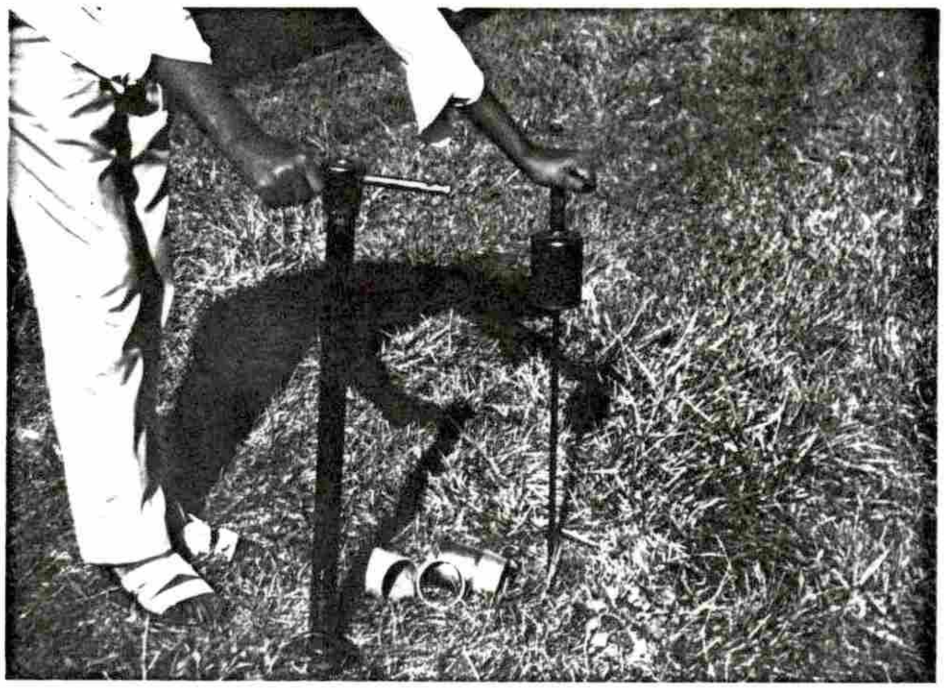


Figure 4. UhLand core sampler used for core sampling for bulk density determination

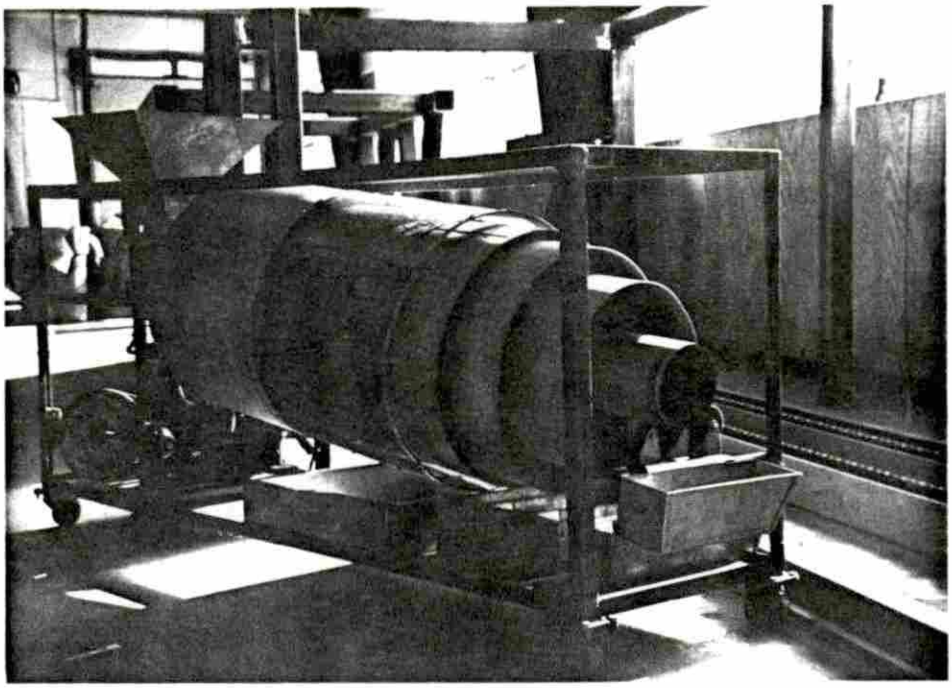


Figure 5. Rotary sieve used for sieving soil samples to different size fractions

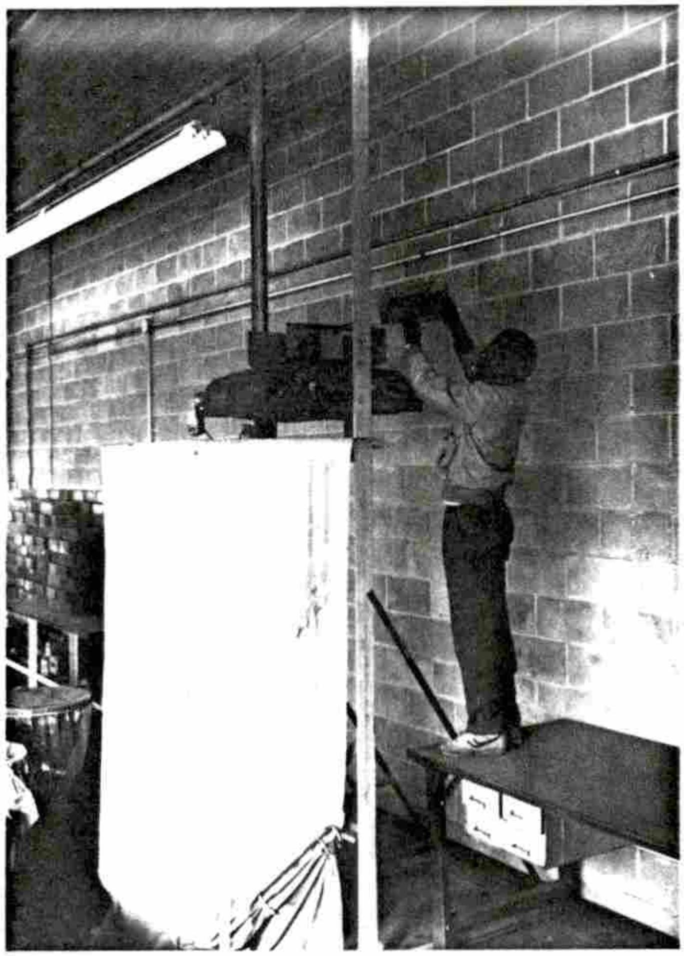
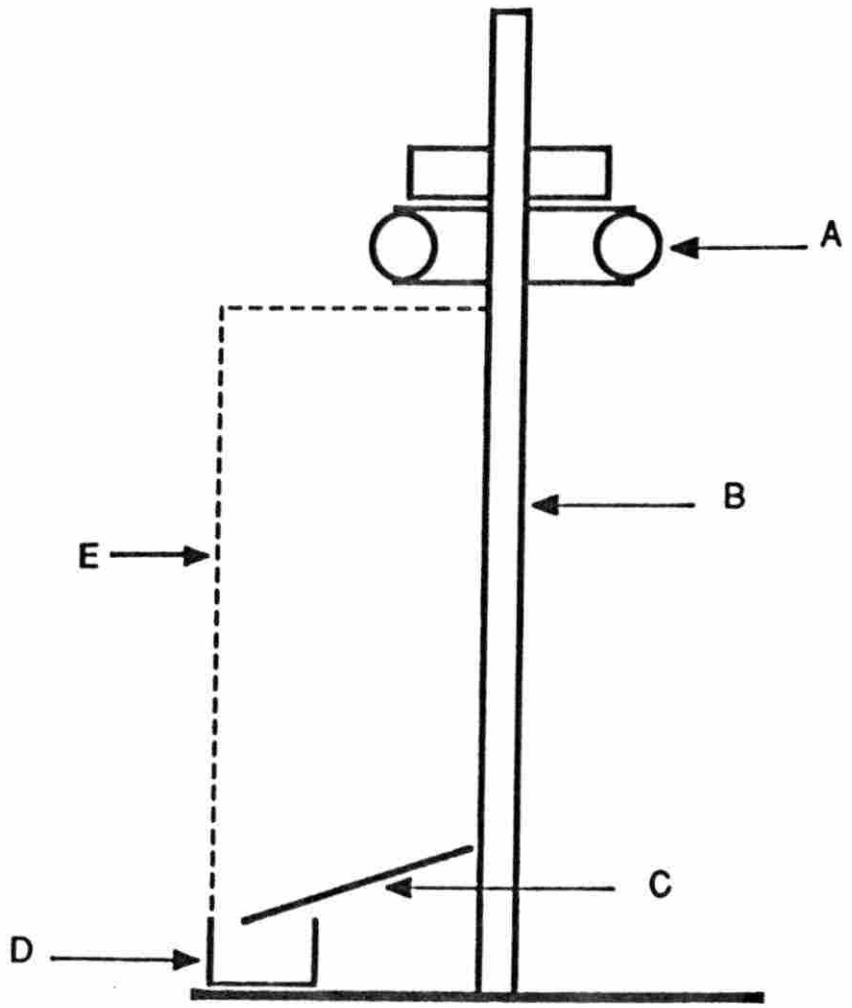


Figure 6. Soil dropper used for the drop-shatter test



A. Metering device B. Supporting frame

C. Rigid sheet metal plate D. Tray to catch dropped soil

E. Curtain to contain shuttered soil

Figure 7. Schematic diagram of the soil dropper used for the drop-shatter test of aggregate stability

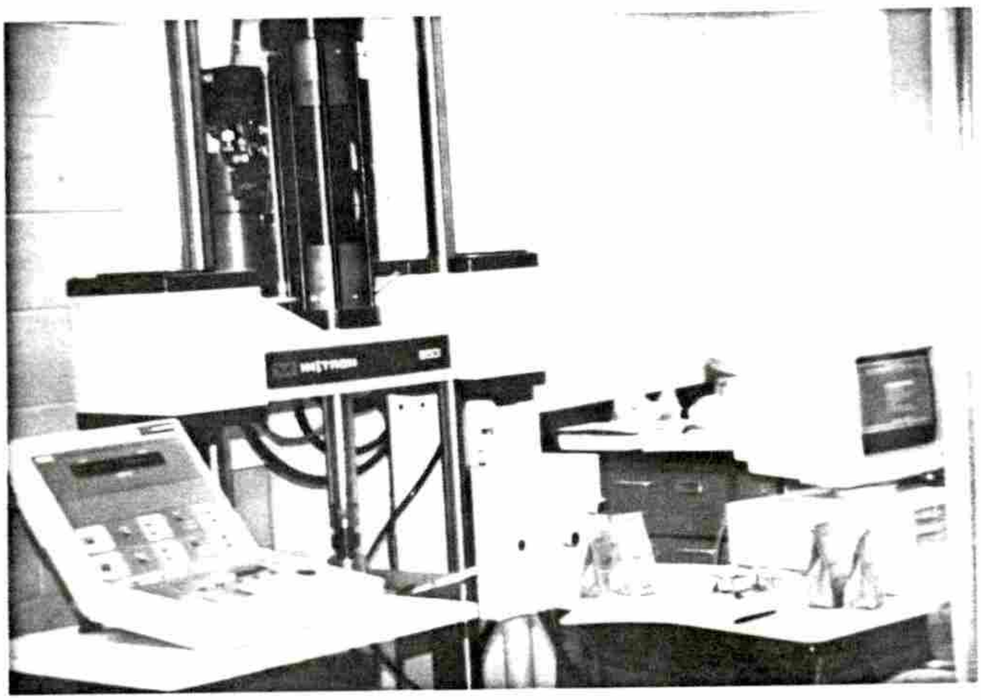


Figure 8. Instron used for aggregates crushing

CHAPTER V. RESULTS AND DISCUSSION

Moisture Content

The average moisture content at time of tillage were 12.8, 13.2, 15.5 and 21.0 percent at 0 - 5 cm depth and 14.9, *[1], 16.0 and 22.3 percent at 5 - 10 cm depth. Statistical analysis showed that 12.8 and 13.2 % were not significantly different. However, 15.5 and 21.0 percent were different and were greater than 12.8 and 13.24 % moisture contents.

Bulk Density

The mean bulk densities for the plots treated were 1.21, *, 1.15 and 1.16 g/cm^3 for plots tilled with disk harrow, and 1.10, *, 1.2 and 1.2 g/cm^3 for plots tilled with field cultivator. The overall bulk densities of the plots tilled at four levels of moisture content were 1.16, *, 1.18 and 1.16 g/cm^3. These bulk densities indicated that the soil of the experimental site was not compacted at tillage time.

Aggregate Size Distribution

The aggregate size distribution data are summarized in Table C.1. The analysis of variance for the data showed that aggregate size distribution of samples taken prior to tillage was not significantly affected by the soil moisture content (Table D.1). However, the mean weight diameters of samples taken after tillage were significantly affected, at 1% level, by both moisture content and tillage implement (Table D.2). This indicates that moisture content at time of tillage and the type of tillage implement used do affect the mean weight diameter of aggregates formed. The results obtained for aggregate size distribution formed with the above mentioned

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[1]Indicates that measurement was not made.

tillage implements agree quite well with those obtained by Lyles and Woodruff (1962) and Dan (1963). For both tillage implements (Figures 9 and 10), the average mean weight diameter after tillage was greater than that before tillage, except for field cultivator at 15.5 % moisture content. At 12.8, 13.2 and 15.5 % moisture content, for disk harrow, the mean weight diameters of aggregates formed were less than those formed at 21.0 % moisture content. Field cultivator also formed aggregates greater in mean-weight-diameter, at the highest moisture content than those formed at lower moisture contents. Therefore tillage at moisture contents below the lower-plastic-limit (19.7 % w/w) formed aggregates with smaller mean-weight-diameter than aggregates formed at moisture content above the lower plastic limit.

Figure 11 shows that, for all levels of moisture content, the disk harrow formed aggregates of greater mean-weight-diameter than the field cultivator. Both moisture content and tillage implement had a significant effect on the size distribution of aggregates formed. However, there was no significant interactive effect between moisture content and tillage implement.

Aggregate Mechanical Stability

Data for aggregate mechanical stability, as determined by the difference in mean weight diameter of the dropped and undropped soil samples, are summarized in Table C.1. Moisture content shows no significant effect on aggregate mechanical stability for samples taken before tillage (Table D.3). However, stability for samples taken after tillage was significantly affected, at 5 % level, by moisture content at time of tillage (Table D.4).

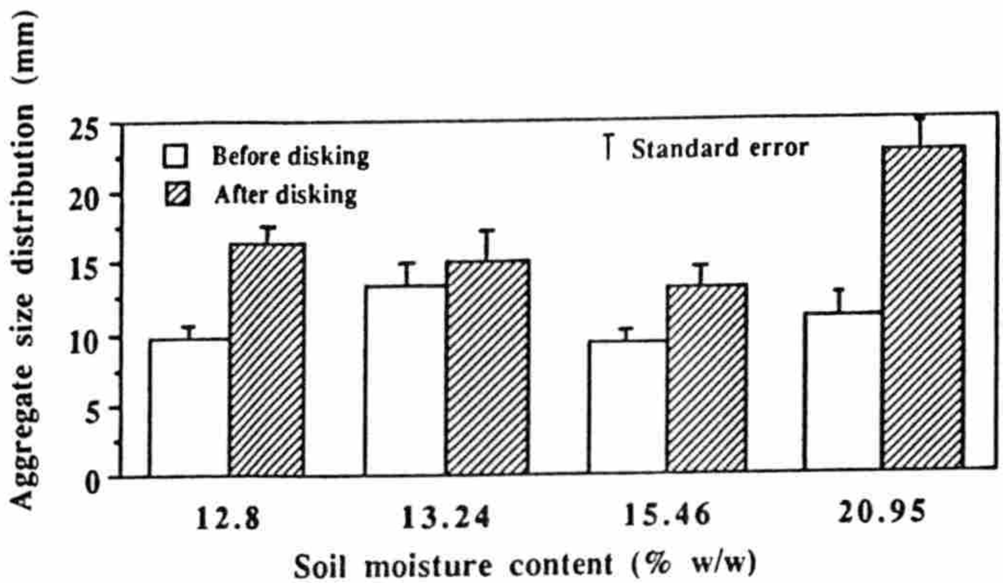

Figure 9. Aggregate size distribution of samples taken before and after disking

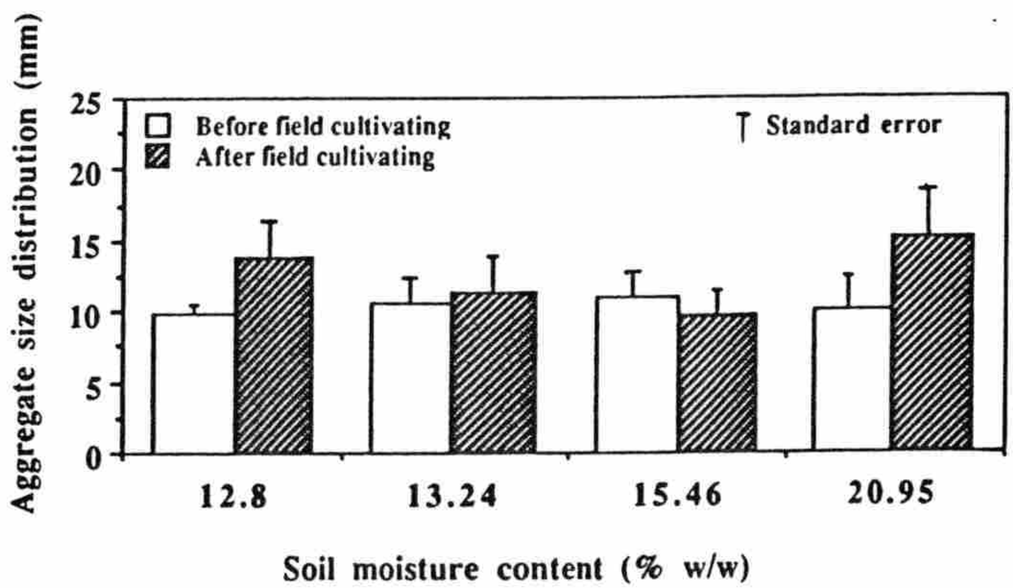

Figure 10. Aggregate size distribution of samples taken before and after field cultivating

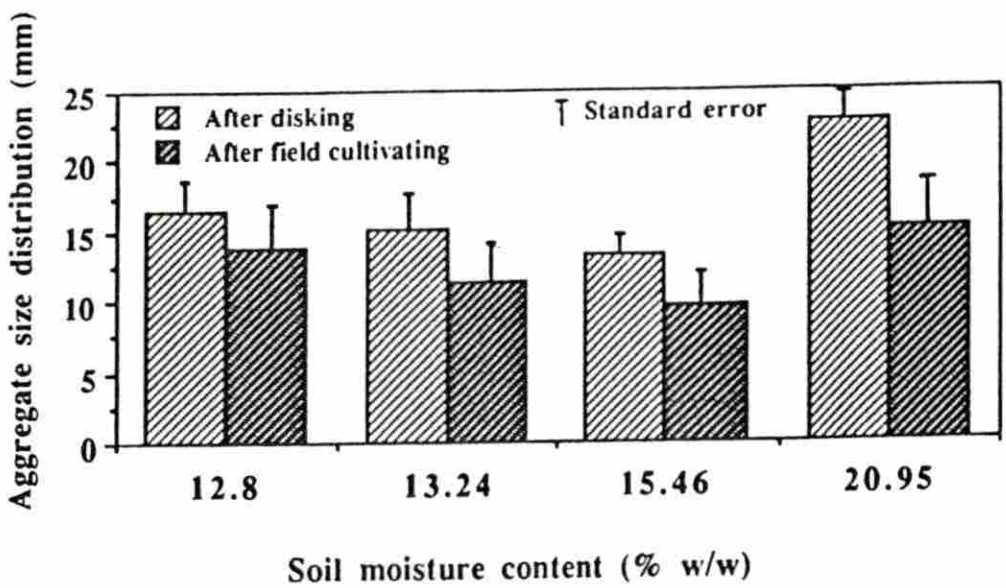

Figure 11. Aggregate size distribution of soil samples taken after disking and field cultivating

Figure 12 shows that aggregates of plots disked at relatively low moisture contents (12.8 - 15.5 %) had greater mechanical stability than plots disked at fairly high moisture content (21.0 %). This is also true for plots tilled with field cultivator (Figure 13). This indicates that aggregates formed at moisture content less than the lower plastic limit, PL (19.7 % w/w) are more stable than aggregates formed at moisture content above the lower plastic limit. Dropping caused a greater decrease in mean-weight-diameter of disked soil than field cultivated soil (Figure 14). This indicates that aggregates formed by field cultivator may be more stable than those formed by disk harrow. However, the implement-type effect on aggregate mechanical stability was significant at only 18 % level (Table D.4).

The result of aggregate mechanical stability agrees, to some extent, with the result of the aggregate size distribution. At moisture contents above the lower plastic limit, aggregates formed were relatively larger in size and less stable as compared to the aggregates formed at moisture content below the lower plastic limit.

Aggregate Crushing Energy and Maximum Force

The crushing energy and the maximum force data for the dropped and undropped aggregate samples, which had passed through 12.7 mm (0.5 in) and were retained on 6.35 mm (0.25 in) screens of the rotary sieve, are summarized in Table C.2. The statistical analysis showed that both the crushing energy and the maximum force were not significantly affected either by the soil moisture content at time of tillage or by the type of tillage implement used (Tables D.5 and D.6). Conversely, the maximum force

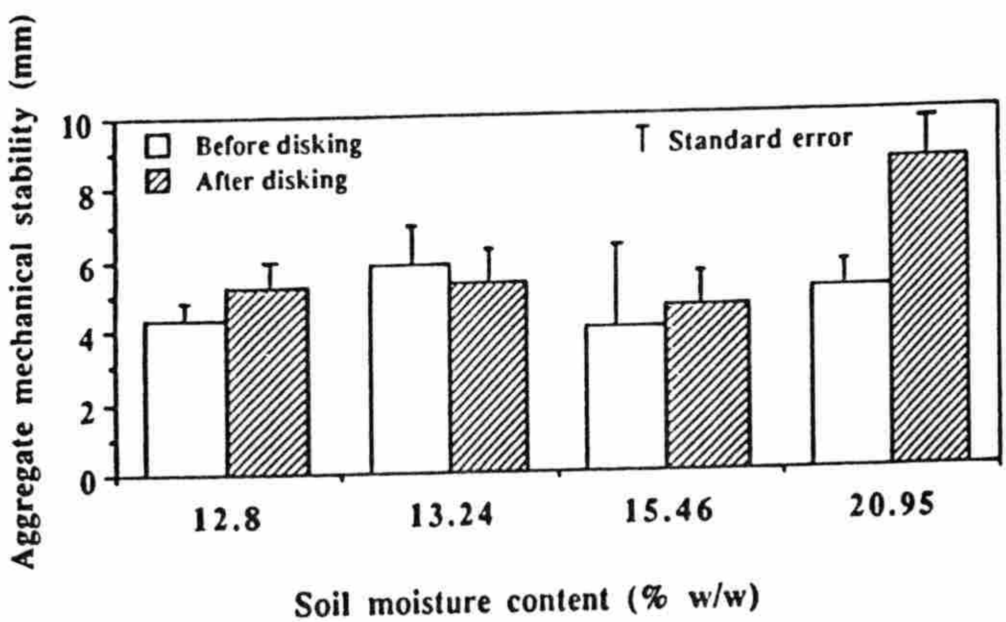

Figure 12. Aggregate stability of soil samples taken before and after disking

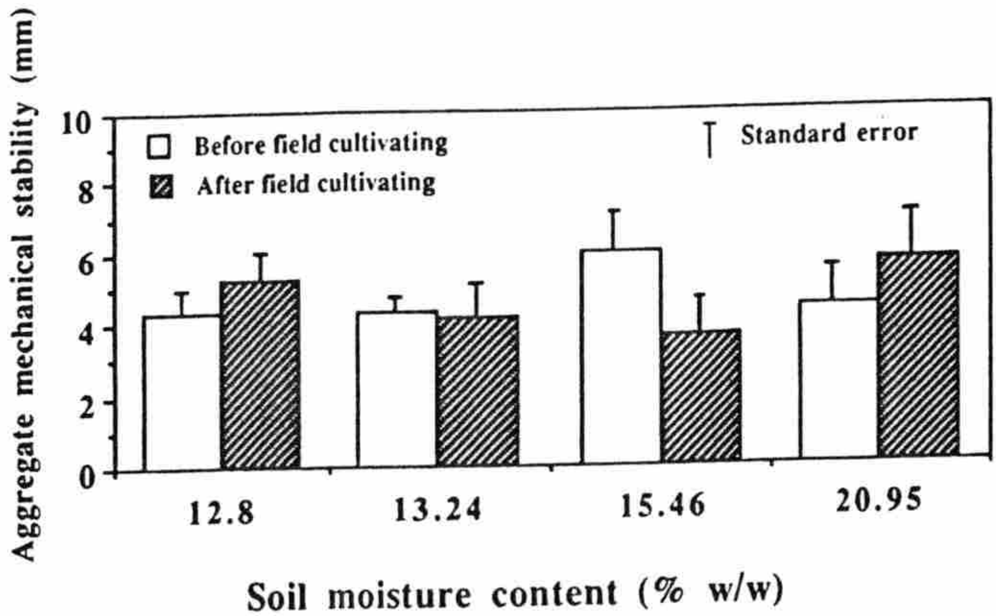

Figure 13. Aggregate stability of soil samples taken before and after field cultivating

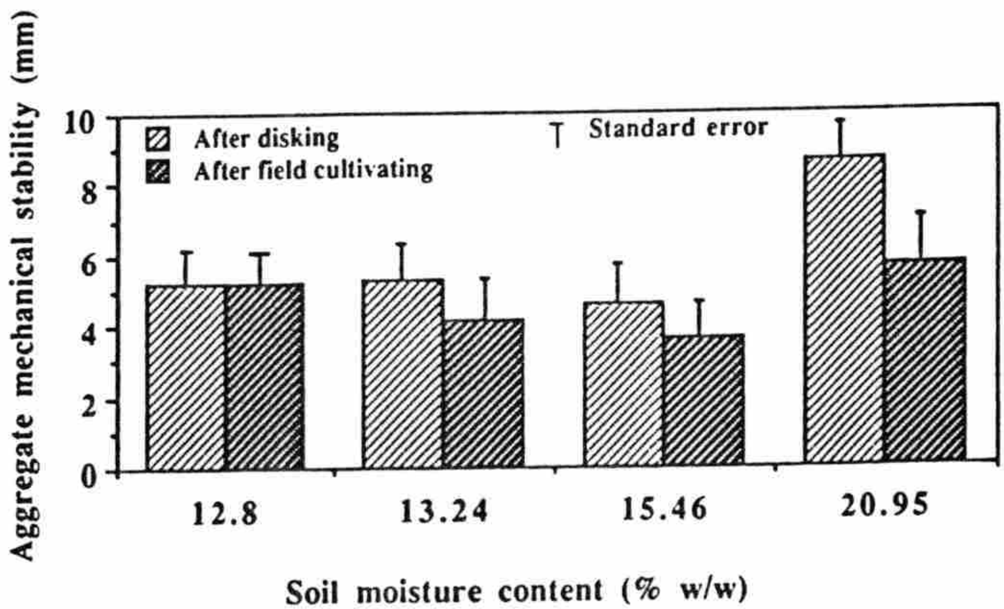

Figure 14. Aggregate stability of soil samples taken after disking and field cultivating

to crush aggregates that passed through 25.4 mm (1 in) and were retained on 12.7 mm (0.5 in) screens, was significantly affected at the 1 % level, by both soil moisture content at time of tillage and tillage implement (Table D.7). However, the crushing energy due to moisture content effect was significant only at the 10 % level (Table D.8). There was no significant interactive effect between moisture content and the tillage implement for either the maximum force or crushing energy.

This indicates that moisture content and implement type do affect the maximum force required to break aggregates, while the crushing energy seems to be affected only by moisture content at the time of tillage.

For instance, Table 2 shows that undropped aggregate samples, which were formed at 12.8, 13.24, and 15.46 % moisture contents were crushed at an energy and a maximum force far less than those formed at 21.0 % moisture content. This is true for dropped samples as well. This result disagrees to some extent with the findings of Lyles and Woodruff (1962). They reported that aggregates formed at low moisture content had more resistance to crushing than those formed at higher moisture content (greater than 16 %). However, they also concluded that resistance to crushing may decrease with drying if the soil is tilled at low moisture content.

Soil at all levels of moisture content tilled with a disk harrow resulted in aggregates that could withstand a larger maximum force than that of soil tilled with the field cultivator (Table 2). There was no significant difference in crushing energy due to implement-type effect.

Table 2. Maximum force and crushing energy of aggregates that passed through 25.4 mm (1 in) screen and were retained on 12.7 mm (0.5 in) screen

Implt. type	Initial soil moisture content	Undropped samples				Dropped samples			
		Before tillage		After tillage		Before tillage		After tillage	
		Max.F[a]	Eng.[b]	Max.F	Eng.	Max.F	Eng.	Max.F	Eng.
	% w/w[c]	N[d]	J[e]	N	J	N	J	N	J
	12.4	52.01	0.106	39.53	0.069	46.25	0.057	57.30	0.117
D	13.4	43.65	0.074	46.82	0.085	33.06	0.038	47.97	0.076
	15.4	46.24	0.076	48.64	0.083	49.58	0.099	54.20	0.090
	20.9	56.99	0.085	66.68	0.076	42.92	0.092	74.14	0.105
Avg		49.72	0.085	50.42	0.078	42.95	0.072	58.40	0.097
	12.4	38.74	0.048	27.99	0.056	34.57	0.107	36.13	0.078
FC	13.4	28.16	0.079	28.47	0.047	27.81	0.037	34.80	0.051
	15.4	37.92	0.073	57.47	0.176	29.26	0.040	33.17	0.075
	20.9	56.43	0.097	71.82	0.092	40.33	0.061	40.83	0.054
Avg		40.31	0.074	46.44	0.093	32.99	0.061	36.23	0.065
LSD(P=0.05)*		9.82	0.026	9.82	0.026	9.82	0.026	9.82	0.026
LSD(P=0.05)**		6.94	NS	6.94	NS	6.94	NS	6.94	NS

[a]Maximum force the crushed aggregates experienced.

[b]Energy required to crush aggregate.

[c]Moisture content on dry basis.

[d]Force in Newtons.

[e]Energy in Joules.

*Between moisture contents at same implement.

**Between implements.

CHAPTER VI. SUMMARY AND CONCLUSIONS

The effect of tillage with disk harrow or field cultivator on change in aggregation of soil tilled at different levels of moisture content was determined. Both the soil moisture content and tillage implement greatly influenced the aggregate size distribution and maximum force during crushing, while the stability and the crushing energy were significantly affected by the moisture content rather than by tillage implement type.

The following specific conclusions were drawn from the study:

1. Moisture content at time of tillage has a significant effect on aggregate size distribution.
2. Aggregates formed at moisture content above the lower plastic limit were larger and less stable than aggregates formed at moisture contents below the lower plastic limit.
3. Type of tillage implement has a significant effect on aggregate size distribution, but has no apparent effect on the stability of aggregates formed.
4. The maximum force at which the aggregates crush was significantly affected by moisture content at the time of tillage and by implement type.
5. The energy to crush is significantly affected by the moisture content at the time of tillage. However, implement type showed no significant effect on crushing energy.

Suggested Future Work

Results obtained in this investigation were from two different types of tillage implement and on only one soil type. The treatments included only four levels of moisture contents. Future research should focus on changes in soil aggregation for all basic tillage implements, for other soil types, and for various soil moisture contents.

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APPENDIX A. ADDITIONAL RELATED STUDIES

Russell (1938) cited some work by Russian researchers that showed that if the soil is tilled at too high moisture content, large clods will be formed, but if tilled at too low moisture the main effect of tillage may be reduction in size of existing aggregates. Utomo and Dexter (1981) found that soil was most friable when the water content of the soil was at about the lower plastic limit. Clods then broke easily into smaller fragments, but not into dust. Russell (1948) defined the optimum moisture content as that "sufficient to fill all the soil pores with water", and he also concluded that the more intensive the tillage, the lower is the optimum content needed to produce stable aggregates. Cole (1939) used aggregate size distribution as the indicator of the degree of pulverization of Yolo loam soil produced by tillage. He found that more small aggregates and fewer large clods were produced when tillage was done between 17 and 20 percent water content than when the water content was greater than 20 percent.

McCalla et al. (1957) studied the influence of various factors, including moisture content (10, 15, 20, 25, and 30 % oven-dry basis) on aggregation of Peorian loess soil by microorganisms. He recorded that in all cases an increase of moisture content from 10 to 20 % resulted in a substantial increase in aggregation, and in general, an increase of moisture content above the 25 % level, which was slightly higher than moisture at 1/3 atmospheres tension (21.3 %), did not appreciably influence the degree of aggregation. Burwell et al. (1966) conducted an experiment to investigate the structural alteration of soil surface by tillage and rainfall. They noticed that soil moisture content at the time of tillage influenced random roughness. Excessively wet or dry condition at time of tillage resulted in greater random roughness than when tillage was performed at a moisture level that provided a friable soil consistency. Allmaras et al. (1969) investigated the influence of aggregates formed as a function of water content at time of tillage on surface roughness. They found that the minimum surface roughness occurred in most cases when tillage was done at the plastic limit. Bhusan and Ghildyal (1972) examined the mean weight diameters of aggregates produced by tillage. They tilled a lateritic sandy loam with seven different implements. Tillage was done at gravimetric water contents of 5.6, 7.2, and 9.2 %. They found that the initial moisture content of the soil affected the magnitude of larger clods. And the coarser seedbed was more often produced when the soil was worked in comparatively dry conditions. The mean-weight-diameters of clods were 16.55 mm and 10.05 mm at 5.6 and 9.2 percent moisture content, respectively, whereas it was least (8.88 mm) at 7.2 percent moisture content. Under all treatments smaller clods were formed at 7.2 percent moisture content although there were differences among implements. Hoyle et al. (1972) controlled the water content of soil during tillage by wetting the soil with sprinklers and allowing the soil to dry to different water contents. They defined aggresizing as "working the soil at appropriate water content". When the soil was wet, the cultivator broke up large clods, and bound fine particles (< 0.5 mm diameter) into aggregates no larger than 12 mm diameter. Adem et al. (1984) found from an experiment conducted to investigate the effect of moisture content of soil at tillage time on size-distribution, that there was a relationship between water content at time of tillage and the percentage of aggregates < 0.5 mm diameter and 10 - 20 mm diameter. They found that as the water content of the soil increased from 13 to 22 % (0.66 PL to 1.12 PL), the percentage of aggregates < 0.5 mm diameter decreased by 44 % and the percentage of aggregates 10 - 20 % mm diameter increased by 34 %. Therefore, as the water content increased, tillage either bound more aggregates < 0.5 mm diameter into larger aggregates, or broke up fewer aggregates 10 - 20 mm diameter into finer aggregates. Neba et al. (1990) conducted a field experiment on a silty clay loam soil to determine the degree to which soil moisture content, at the time of tillage, affects aggregate size distribution resulting from tillage. They used a point chisel for tillage treatments on consolidated soil and an offset disk on the unconsolidated soil. Tillage was performed at three different gravimetric soil moisture contents ranging from 25.5 % to 19.1 % for the consolidated treatment and from 25.5 % to 14.6 % for the unconsolidated treatment. They noticed that the fraction of large aggregates (>19 mm), formed by chiseling the consolidated soil appears to decrease as soil moisture content, at the time of tillage, decreased from 25.5 % to 19.1 %. The amount of aggregates in the largest size class (76.2 mm), in the unconsolidated soil tests, are less for all offset disk tillage treatments. However, the amount of large aggregates in the largest size class that are broken into smaller sizes does not monotonically increase as soil moisture content at the time of tillage decreases. They concluded that soil moisture content at the time of tillage has significant effect on soil aggregate size distribution. They also concluded that the point chisel appears to create larger aggregates at high moisture content under the consolidated pre-tillage soil condition. The offset disk tends to break down large aggregates under the unconsolidated pre-tillage soil condition regardless of soil moisture content.

Johnson et al. (1979) reported that clods formed by moldboard plowing wet soil were unstable compared to clods formed with soil nearer the lower plastic limit and these differences persisted over a series of simulated storms. They also reported that the effect of soil moisture at time of tillage persisted over several rainstorms. This was attributed to the greater roughness obtained when plowing soil of a friable consistency than when plowing soil of a liquid consistency.

Zobeck and Popham (1990) conducted an experiment on four Texas sandy soils to investigate the influence of tillage and precipitation on aggregate size distribution. Tillage methods they used included moldboard plow, lister, chisel, and tandem disk. Because detailed soil water measurements were not available for the duration of the study, calculations of cumulative precipitation prior to and including date of sampling were used as an index of soil moisture content. They concluded that tillage and precipitation produced significant differences in aggregate size distribution on sandy soils in west Texas. They also concluded that implements created a substantial number of large stabile aggregates, such as the moldboard plow, produced a significantly different distribution of aggregates, compared with other tillage implements tested. Tisdall and Adem (1986) conducted a field experiment on a silty soil to investigate the effect of water content of soil at tillage on the size distribution of aggregates, and on infiltration. They allowed the soil to dry for 7 days after 46 mm rain. Then, every 1 - 4 days, depending on the drying rate of the soil, and for up to 25 days, a spring-tined cultivator tilled one bed at random, in two passes to a depth of 0.15 m. This gave a total of 16 treatments, separated by guard rows, of soil tilled at water contents ranging from 11 to 24 %(w/w). They found a significant relationship between the water content of the soil at tillage and the percentage of aggregates < 0.5 mm, 0.5 - 1 mm. 1 - 2 mm and > 20 mm diameter. They concluded that as the water content at tillage increased from 11 to 24 % the percentage of aggregates > 20 mm diameter increased, and the percentage of aggregates in all other size-ranges decreased. They finally concluded that as the soil water content was increased, tillage either bound more aggregates of < 20 mm diameter into larger aggregates, or broke up fewer aggregates of > 20 mm diameter into finer aggregates.

A preliminary experiment was conducted at the Agricultural Engineering Research Center near Ames, Iowa, on a field near the main experiment. Three tillage treatments were compared. They were moldboard plowing followed by disking, disking followed by ridging and cultivating with sweeps. Tillage was performed at gravimetric soil moisture content of 19.8 % a 27.5 % for soil depths 0-5 and 5-10 cm, respectively. Aggregate samples were taken before and after tillage. They were allowed to air dry, then sieved with the rotary sieve to six size fractions. The mean-weight-diameter was calculated for each sample, and used as an index for aggregate size distribution. The stability of the aggregates was determined by the difference in mean-weight-diameter of dropped and undropped soil samples.

The statistical analysis showed that aggregate size distribution was significantly affected by tillage. This indicates that implement type has an effect on soil aggregate formed. Disking followed by ridging formed aggregates of 3.29 cm mean-weight-diameter, followed by moldboard plowing plus disking 3.22 cm. Sweep plowing formed aggregates with the smallest mean-weight-diameter of 2.39 cm.

The statistical analysis indicated that implement type has no significant effect on aggregate stability; conversely, a 5% level of significance was found when aggregate mean-weight-diameter before and after tillage were compared. The mean-weight-diameter reduction caused by drop shatter of soil before tillage was 0.35 cm, while reduction for soil after tillage was 0.70 cm. This indicates that, for given soil conditions, tillage greatly decreased the stability of aggregates. No significant difference in aggregate stability could be attributed to effect of implement type.

APPENDIX B. DESCRIPTION OF EQUIPMENT USED

Tillage equipment consisted of a disk harrow and a field cultivator to till the soil. Sampling equipment used to obtain the required measurements were a hand operated soil sampling tube, a UhLand core sampler, plastic trays and a spade. Samples were processed with a rotary sieve, a soil dropper and an aggregate crusher.

Tillage equipment

Disk harrow   A John Deere[1], Model 620, 3.6-meter (12-ft), tandem, wheel-type, rigid frame disk harrow (Figure 2). Plain disk blades were used on both front and rear gangs. The spacing and the diameter of the disk blades were 22.5 cm and 45 cm (9 and 18 in), respectively. The disk angle with respect to the direction of travel and the operating depth were kept constant at approximately 20 degrees with direction of travel and 10 cm (4 in), respectively. No additional weight or attachments were used on the disk harrow.

Field cultivator   A John Deere C-shank field cultivator (Figure 3), Model C-11, 3.81-meter (12.5-ft) width with two wheels, triple-bar frame of 6.25-cm (2.5-in) tubular steel, 3 cross bars with 4, 6, and 5 shanks on the front, middle and rear cross bar, respectively. Each shank was equipped with a 17.5-cm (7-in) width sweep type blade.

Soil sampling equipment

Soil sampling tube   A 2.5-cm diameter hand operated soil sampling tube was used to sample soil for determination of soil moisture contents.

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[1]Mention of companies or commercial products does not imply recommendation or endorsement by the USDA or Iowa State University over others not mentioned.

The soil sampling tube was inserted to the depth of 10 cm and the core of soil removed was partitioned into 0 - 5 and 5 - 10 cm depth increments. A composite soil sample was collected from several randomly determined points within each plot. The samples were then weighed, oven-dried and reweighed for the determination of the moisture content.

Core sampler Figure 4 shows a hand-operated UhLand core sampler used for bulk density determination. The core sampler consisted of a tightly fitting cover, a soil sampling cylinder of 7.5 cm diameter and 7.5 cm operating depth, anvil with sliding rod and a sliding hammer of 5 kg mass. The core sampler was driven into soil with blows from the hammer. Cores were taken from 0 - 7.5 cm soil surface at random points within each plot. They were dug out, cut smooth at both ends and weighed. The cores were then oven-dried at 105 deg. C for 24 hours, reweighed, and water content bulk density calculated.

Aggregate sampling equipment A flat spade was used to take approximately 2 kg soil sample slices to the depth of 10 cm for samples before tillage, and to the depth of tillage at random points from each plot. The samples were placed in rectangular plastic containers and transported to the laboratory to air dry.

Soil processing equipment

Rotary sieve The rotary sieve used for the determination of aggregate size distribution was similar to that used by Chepil and Bisal (1943), Swamy et al. (1960), and Gill and McGreery (1960). Figure 5 shows the sieve with its concentric cylinders. The screens were attached to the cylinders such that the smallest screen was on the largest cylinder and the largest screen on the smallest cylinder. The sieve was aligned downward at

4 degrees for efficient sieving. An electric gear motor was used to drive the rotary sieve at 33 rev/min. The total weight of a soil sample was determined prior to sieving. Only clods smaller than 7.5 cm (3 in) in diameter could pass through the rotary sieve openings; hence clods larger than 7.5 cm (3 in) diameter were removed from the sample by hand and placed into a tray for weighing. Residue found in the sample was removed and weighed and subtracted from the initial total soil weight. After the sample was sieved, each size range was weighed and its weight was recorded. The mean weight diameter was computed for each sample and used as an index to express the distribution of aggregate size (Van Bavel, 1949; Youker and McGuinness, 1956).

Soil dropper The soil dropper (Figure 6) was used for determining the mechanical aggregate stability. It is based on the drop-shatter test (Marshall and Quirk, 1950; Ingles, 1963; Hadas, 1984). Basically, this test measures how much soil break-up will occur with a certain energy impact. It has been used to assess the performance of the impact-type tillage tools. The soil dropper used for this study dropped the soil sample from a 2 meter height (Hadas and Wolf, 1984) onto a solid metal sheet tilted at 30 degrees to the horizontal. After impact the soil flowed to a collection pan. This avoided the impact of the falling aggregates on the soil previously dropped. The difference in mean weight diameter of dropped and undropped aggregates was used to indicate aggregate stability. The soil dropper consists of a metering device, a solid sheet metal plate, the supporting frame and a tray to catch the dropped soil. The metering device was belt driven slowly by an electric motor rotating at speed of 3.6 rev/min. The height of dropping could be adjusted from less than 0.5 to 3.0 meters.

APPENDIX C: RAW DATA

Table C.1. Moisture content and implement effect on aggregate size distribution and aggregate stability

Implt. type	Initial soil moisture content 0-5 cm depth	Initial soil moisture content 5-10 cm depth	Initial bulk density	Mean-weight-diameter (MWD) BT[a]	MWD AT[b]	Change in MWD	Aggregate mechanical stability (AMS) BT	AMS AT	Change in AMS
	... % w/w[c] ...		Mg/m^3	.... mm			.... mm		
	12.8	14.9	1.21	9.8	16.5	6.7	4.3	5.2	0.9
D	13.24	-[d]	-	13.4	15.1	1.7	5.8	5.3	- 0.5
	15.46	16.0	1.15	9.4	13.2	3.8	4.0	4.6	0.6
	20.95	22.3	1.16	11.1	22.8	11.7	5.1	8.6	3.5
Avg.	15.61	17.7	1.17	10.9	16.9	6.0	4.8	5.9	1.1
	12.8	14.9	1.10	9.8	13.9	4.1	4.3	5.2	0.9
FC	13.24	-[b]	-	10.7	11.3	0.6	4.3	4.2	- 0.1
	15.46	16.0	1.20	11.0	9.7	- 1.3	6.0	3.6	- 2.4
	20.95	22.3	1.20	10.1	15.2	5.1	4.4	5.7	1.3
Avg.	15.61	17.7	1.17	10.4	12.5	2.1	4.7	4.7	- 0.1
LSD(P=0.05)*				2.3	3.9		1.4	2.7	
LSD(P=0.05)**					2.7			1.8	

[a]Before tillage.

[b]After tillage.

[c]Moisture content on dry basis.

[d]Indicates that measurement was not made.

*Between moisture contents at same or different implement.

**Between implements.

Table C.2. Maximum force and crushing energy of aggregates that passed through 12.7 mm (0.5 in) screen and were retained on 6.35 mm (0.25 in) screen

Implt type	Initial soil moisture content	Undropped samples				Dropped samples			
		Before Tillage		After Tillage		Before Tillage		After Tillage	
		Max.F[a]	Eng.[b]	Max.F	Eng.	Max.F	Eng.	Max.F	Eng.
	% w/w[c]	N[d]	J[e]	N	J	N	J	N	J
	12.4	17.51	0.028	17.22	0.035	13.82	0.017	18.95	0.020
D	13.4	22.62	0.031	12.98	0.045	16.95	0.015	21.01	0.042
	15.4	19.45	0.030	15.56	0.026	14.90	0.019	19.88	0.025
	20.9	20.87	0.037	17.54	0.023	28.23	0.042	29.11	0.026
Avg		20.11	0.032	15.83	0.032	18.48	0.023	22.24	0.028
	12.4	17.40	0.033	12.50	0.047	20.70	0.018	35.59	0.023
FC	13.4	20.41	0.027	20.82	0.041	18.67	0.034	30.00	0.012
	15.4	20.35	0.033	15.80	0.019	16.51	0.019	21.29	0.019
	20.9	21.54	0.038	20.50	0.036	19.90	0.023	25.84	0.036
Avg		19.93	0.033	17.41	0.036	18.95	0.024	28.18	0.023
LSD(P=0.05)*		NS	NS	NS	NS	NS	NS	NS	NS
LSD(P=0.05)**		NS	NS	NS	NS	NS	NS	NS	NS

[a]Maximum force the crushed aggregate experienced.

[b]Energy required to crush the aggregate.

[c]Moisture content on dry basis.

[d]Force in Newton.

[e]Energy in Joules.

*Between moisture contents at same or different implements.

**Between implements.

Table C.3. Soil moisture contents of the plots before tillage treatments

Block number	Treatment number	Initial soil moisture content 0 - 5 cm depth	5 - 10 cm depth
Date: August 29, 1989			
		.... % w/w	....
I	T1	15.14	17.24
I	T1	14.66	15.46
I	T1	15.30	15.41
I	T1	14.55	14.04
I	T1	12.93	15.16
II	T1	11.03	14.35
II	T1	11.46	13.31
II	T1	12.59	17.27
II	T1	14.85	14.91
II	T1	11.37	14.72
III	T1	10.83	14.14
III	T1	11.09	14.99
III	T1	11.23	14.09
III	T1	12.81	14.30
III	T1	11.77	14.38
IV	T1	12.62	15.65
IV	T1	12.11	15.19
IV	T1	13.46	14.65
IV	T1	12.74	14.95
IV	T1	13.50	13.93
Date: August 22, 1989			
I	T2	13.13	_
I	T2	12.65	_
I	T2	13.69	_
I	T2	13.41	_
I	T2	13.93	_
II	T2	13.91	_
II	T2	12.34	_
II	T2	14.49	_
II	T2	13.53	_
II	T2	11.79	_
III	T2	13.79	_
III	T2	13.26	_
III	T2	13.62	_
III	T2	13.62	_

Table C.3 (Continued)

Block number	Treatment number	Initial soil moisture content	
		0 - 5 cm depth	5 - 10 cm depth
III	T2	14.14	–
IV	T2	13.07	–
IV	T2	12.74	–
IV	T2	13.50	–
IV	T2	11.81	–
IV	T2	12.40	–
Date: September 5, 1989			
I	T3	17.27	18.75
I	T3	16.40	19.18
I	T3	16.23	18.67
I	T3	16.02	17.22
I	T3	14.83	17.18
II	T3	15.18	18.29
II	T3	15.51	17.02
II	T3	14.66	17.29
II	T3	14.62	18.16
II	T3	14.35	16.51
III	T3	15.86	17.52
III	T3	17.89	18.10
III	T3	15.37	18.30
III	T3	15.37	18.59
III	T3	17.89	19.08
IV	T3	14.98	17.76
IV	T3	15.58	17.53
IV	T3	14.54	16.44
IV	T3	13.42	16.58
IV	T3	13.14	16.23
Date: October 30, 1989			
I	T4	20.39	21.84
I	T4	20.77	21.79
I	T4	22.00	22.12
I	T4	20.71	20.81
I	T4	21.41	22.70
II	T4	19.60	20.14
II	T4	20.24	22.29
II	T4	21.29	23.06

Table C.3 (Continued)

Block number	Treatment number	Initial soil moisture content	
		0 - 5 cm depth	5 - 10 cm depth
II	T4	21.07	22.15
II	T4	22.15	22.90
III	T4	21.16	21.23
III	T4	20.90	21.39
III	T4	22.31	22.39
III	T4	21.50	22.90
III	T4	21.79	22.38
IV	T4	21.43	20.99
IV	T4	20.24	21.09
IV	T4	20.91	19.99
IV	T4	20.05	19.30
IV	T4	19.10	20.06

Table C.4. Weight of size fractions of soil samples before dropping

Implt. Type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
Date: August 29, 1989								
Moisture content: 12.80 %								
			.... gm					
FC	BT	I	1080.00	187.00	260.00	298.00	121.00	0.00
		I	966.00	149.00	217.00	276.00	193.00	0.00
		I	919.00	123.00	173.00	200.00	154.00	0.00
		I	784.00	130.00	216.00	297.00	418.00	0.00
		I	1081.00	157.00	220.00	308.00	79.00	0.00
	AT	I	1326.00	192.00	253.00	288.00	263.00	0.00
		I	933.00	172.00	244.00	343.00	304.00	0.00
		I	996.00	169.00	213.00	277.00	365.00	0.00
		I	804.00	194.00	309.00	350.00	406.00	0.00
		I	1089.00	209.00	310.00	324.00	104.00	192.00
D	BT	I	1164.00	243.00	317.00	404.00	412.00	0.00
		I	1150.00	191.00	308.00	422.00	300.00	0.00
		I	528.00	81.00	138.00	143.00	303.00	530.00
		I	999.00	162.00	261.00	346.00	205.00	145.00
		I	885.00	159.00	251.00	316.00	214.00	0.00
	AT	I	1004.00	199.00	320.00	481.00	286.00	0.00
		I	992.00	211.00	286.00	300.00	329.00	0.00
		I	851.00	175.00	241.00	286.00	204.00	0.00
		I	829.00	202.00	261.00	260.00	374.00	0.00
		I	863.00	204.00	323.00	348.00	372.00	0.00
D	BT	II	1021.00	158.00	241.00	288.00	331.00	223.00
		II	1045.00	153.00	215.00	316.00	397.00	0.00
		II	1081.00	204.00	271.00	371.00	335.00	0.00
		II	578.00	101.00	177.00	257.00	583.00	133.00
		II	933.00	165.00	238.00	357.00	159.00	0.00
	AT	II	768.00	197.00	334.00	406.00	274.00	0.00
		II	840.00	187.00	286.00	304.00	294.00	115.00
		II	558.00	137.00	228.00	285.00	463.00	295.00
		II	870.00	186.00	274.00	446.00	519.00	0.00
		II	680.00	170.00	253.00	376.00	493.00	0.00
FC	BT	II	1131.00	179.00	261.00	294.00	279.00	0.00
		II	1105.00	211.00	307.00	349.00	255.00	0.00
		II	1054.00	180.00	250.00	311.00	168.00	0.00
		II	1405.00	259.00	268.00	376.00	234.00	0.00
		II	1251.00	200.00	282.00	379.00	375.00	0.00
	AT	II	962.00	168.00	232.00	275.00	95.00	0.00
		II	985.00	171.00	240.00	239.00	231.00	0.00
		II	1292.00	165.00	203.00	144.00	128.00	0.00

Table C.4 (Continued)

Implt type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
			.... gm					
		II	1088.00	149.00	190.00	209.00	66.00	0.00
		II	1347.00	160.00	204.00	218.00	102.00	0.00
D	BT	III	1133.00	209.00	317.00	405.00	375.00	0.00
		III	1084.00	181.00	264.00	282.00	370.00	0.00
		III	1089.00	181.00	236.00	274.00	199.00	0.00
		III	1350.00	163.00	220.00	286.00	186.00	0.00
		III	1164.00	184.00	259.00	312.00	283.00	0.00
	AT	III	708.00	136.00	202.00	250.00	304.00	61.00
		III	648.00	142.00	216.00	295.00	393.00	141.00
		III	460.00	130.00	241.00	316.00	305.00	103.00
		III	756.00	131.00	160.00	157.00	223.00	0.00
		III	969.00	141.00	189.00	233.00	293.00	0.00
FC	BT	III	773.00	132.00	194.00	203.00	259.00	0.00
		III	1091.00	191.00	275.00	399.00	311.00	0.00
		III	898.00	185.00	242.00	315.00	572.00	0.00
		III	814.00	179.00	311.00	382.00	540.00	15.00
		III	680.00	181.00	309.00	411.00	673.00	0.00
	AT	III	947.00	169.00	231.00	274.00	197.00	0.00
		III	844.00	169.00	286.00	356.00	401.00	0.00
		III	929.00	187.00	284.00	422.00	387.00	130.00
		III	715.00	121.00	179.00	201.00	259.00	263.00
		III	743.00	149.00	211.00	251.00	300.00	0.00
D	BT	IV	1350.00	192.00	254.00	285.00	184.00	132.00
		IV	1113.00	187.00	287.00	355.00	179.00	0.00
		IV	1410.00	233.00	295.00	316.00	314.00	0.00
		IV	1200.00	178.00	243.00	281.00	318.00	0.00
		IV	1268.00	198.00	270.00	309.00	249.00	33.00
	AT	IV	802.00	158.00	234.00	291.00	223.00	0.00
		IV	815.00	159.00	232.00	273.00	348.00	0.00
		IV	817.00	159.00	237.00	274.00	419.00	0.00
		IV	765.00	143.00	193.00	272.00	253.00	0.00
		IV	512.00	112.00	182.00	225.00	433.00	0.00
FC	BT	IV	1137.00	165.00	236.00	243.00	157.00	0.00
		IV	1519.00	188.00	259.00	264.00	156.00	0.00
		IV	1089.00	173.00	251.00	287.00	170.00	0.00
		IV	1645.00	271.00	360.00	366.00	124.00	0.00
		IV	1297.00	192.00	298.00	255.00	240.00	0.00
	AT	IV	1190.00	181.00	287.00	372.00	188.00	0.00
		IV	1103.00	192.00	289.00	277.00	334.00	0.00
		IV	1149.00	199.00	310.00	288.00	123.00	0.00

Table C.4 (Continued)

Implt type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
			gm					
		IV	1130.00	179.00	226.00	247.00	97.00	0.00
		IV	1180.00	189.00	287.00	315.00	91.00	0.00
Date: August 22, 1989								
Moisture content: 13.24 %								
D	BT	I	785.00	135.00	194.00	239.00	260.00	0.00
		I	798.00	115.00	152.00	155.00	118.00	0.00
		I	960.00	350.00	234.00	290.00	225.00	0.00
		I	1050.00	112.00	154.00	162.00	53.00	0.00
		I	844.00	103.00	158.00	157.00	110.00	0.00
	AT	I	662.00	141.00	191.00	236.00	140.00	212.00
		I	488.00	131.00	223.00	259.00	650.00	0.00
		I	389.00	126.00	218.00	284.00	649.00	158.00
		I	858.00	179.00	217.00	278.00	303.00	131.00
		I	693.00	135.00	173.00	163.00	300.00	0.00
FC	BT	I	785.00	135.00	194.00	239.00	260.00	0.00
		I	798.00	115.00	152.00	155.00	118.00	0.00
		I	960.00	350.00	234.00	290.00	225.00	0.00
		I	1050.00	112.00	154.00	162.00	53.00	0.00
		I	844.00	103.00	158.00	157.00	110.00	0.00
	AT	I	554.00	86.00	119.00	154.00	240.00	0.00
		I	788.00	137.00	198.00	247.00	80.00	0.00
		I	719.00	110.00	147.00	158.00	168.00	148.00
		I	570.00	124.00	190.00	211.00	216.00	0.00
		I	980.00	166.00	197.00	272.00	143.00	0.00
FC	BT	II	956.00	137.00	163.00	231.00	204.00	0.00
		II	838.00	117.00	136.00	134.00	140.00	0.00
		II	852.00	114.00	164.00	178.00	79.00	0.00
		II	870.00	110.00	130.00	110.00	86.00	222.00
		II	985.00	110.00	130.00	128.00	68.00	0.00
	AT	II	892.00	127.00	162.00	182.00	166.00	0.00
		II	780.00	129.00	214.00	242.00	216.00	0.00
		II	800.00	135.00	216.00	269.00	302.00	0.00
		II	800.00	145.00	213.00	211.00	275.00	0.00
		II	582.00	140.00	209.00	308.00	258.00	0.00
D	BT	II	956.00	137.00	163.00	231.00	204.00	0.00
		II	838.00	117.00	136.00	134.00	140.00	0.00
		II	852.00	114.00	164.00	178.00	79.00	0.00
		II	870.00	110.00	130.00	110.00	86.00	222.00

Table C.4 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
			.... gm					
		II	985.00	110.00	130.00	128.00	68.00	0.00
	AT	II	476.00	133.00	210.00	290.00	400.00	188.00
		II	639.00	101.00	128.00	173.00	158.00	0.00
		II	446.00	108.00	180.00	229.00	457.00	0.00
		II	726.00	145.00	180.00	152.00	124.00	0.00
		II	549.00	130.00	204.00	293.00	310.00	215.00
D	BT	III	886.00	128.00	170.00	155.00	107.00	0.00
		III	788.00	137.00	198.00	247.00	80.00	0.00
		III	711.00	117.00	167.00	187.00	179.00	0.00
		III	697.00	108.00	162.00	174.00	210.00	0.00
		III	474.00	93.00	136.00	172.00	319.00	0.00
	AT	III	391.00	111.00	195.00	336.00	366.00	0.00
		III	591.00	101.00	128.00	190.00	162.00	0.00
		III	640.00	148.00	231.00	277.00	277.00	0.00
		III	370.00	111.00	210.00	344.00	503.00	0.00
		III	607.00	144.00	203.00	322.00	174.00	109.00
FC	BT	III	886.00	128.00	170.00	155.00	107.00	0.00
		III	788.00	137.00	198.00	247.00	80.00	0.00
		III	711.00	117.00	167.00	187.00	179.00	0.00
		III	697.00	108.00	162.00	174.00	210.00	0.00
		III	474.00	93.00	136.00	172.00	319.00	0.00
	AT	III	384.00	102.00	170.00	276.00	467.00	0.00
		III	371.00	41.00	175.00	276.00	500.00	0.00
		III	327.00	88.00	157.00	239.00	485.00	251.00
		III	509.00	114.00	183.00	341.00	399.00	115.00
		III	1068.00	165.00	207.00	180.00	63.00	0.00
FC	BT	IV	934.00	145.00	176.00	190.00	188.00	0.00
		IV	500.00	104.00	183.00	200.00	223.00	0.00
		IV	771.00	108.00	131.00	194.00	108.00	0.00
		IV	838.00	138.00	177.00	183.00	166.00	0.00
		IV	533.00	93.00	143.00	163.00	481.00	0.00
	AT	IV	633.00	172.00	247.00	234.00	203.00	158.00
		IV	929.00	180.00	239.00	306.00	454.00	0.00
		IV	726.00	134.00	168.00	161.00	99.00	201.00
		IV	872.00	145.00	206.00	239.00	301.00	0.00
		IV	728.00	140.00	204.00	237.00	328.00	0.00
D	BT	IV	934.00	145.00	176.00	190.00	188.00	0.00
		IV	500.00	104.00	183.00	200.00	223.00	0.00
		IV	771.00	108.00	131.00	194.00	108.00	0.00
		IV	838.00	138.00	177.00	183.00	166.00	0.00
		IV	533.00	93.00	143.00	163.00	481.00	0.00

Table C.4 (Continued)

Implt. type	State	Block number	Sieve size (in) 0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
			......	......	......	gm	......	......
	AT	IV	793.00	159.00	217.00	140.00	241.00	232.00
		IV	598.00	137.00	218.00	421.00	220.00	102.00
		IV	396.00	118.00	189.00	207.00	434.00	0.00
		IV	530.00	129.00	209.00	223.00	321.00	0.00
		IV	579.00	136.00	208.00	248.00	304.00	84.00

Date: September 5, 1989
Moisture content: 15.46 %

D	BT	I	678.00	128.00	186.00	243.00	234.00	0.00
		I	578.00	96.00	153.00	212.00	257.00	0.00
		I	695.00	88.00	122.00	125.00	145.00	0.00
		I	650.00	104.00	154.00	193.00	212.00	0.00
		I	650.00	104.00	154.00	193.00	212.00	0.00
	AT	I	268.00	90.00	146.00	223.00	262.00	0.00
		I	375.00	94.00	130.00	206.00	230.00	0.00
		I	464.00	111.00	158.00	207.00	240.00	0.00
		I	680.00	111.00	143.00	110.00	130.00	0.00
		I	551.00	130.00	188.00	209.00	166.00	0.00
FC	BT	I	557.00	83.00	112.00	113.00	81.00	0.00
		I	810.00	140.00	188.00	216.00	237.00	0.00
		I	694.00	111.00	192.00	26.00	28.00	0.00
		I	687.00	111.00	164.00	118.00	115.00	0.00
		I	687.00	111.00	164.00	118.00	115.00	0.00
	AT	I	846.00	122.00	158.00	121.00	30.00	0.00
		I	622.00	79.00	96.00	128.00	87.00	0.00
		I	493.00	85.00	117.00	107.00	101.00	0.00
		I	760.00	142.00	185.00	205.00	87.00	0.00
		I	683.00	99.00	130.00	99.00	61.00	0.00
D	BT	II	627.00	78.00	114.00	95.00	0.00	0.00
		II	755.00	101.00	145.00	88.00	167.00	0.00
		II	569.00	87.00	122.00	147.00	85.00	0.00
		II	650.00	89.00	127.00	110.00	84.00	0.00
		II	650.00	89.00	127.00	110.00	84.00	0.00
	AT	II	478.00	95.00	118.00	148.00	276.00	0.00
		II	300.00	77.00	101.00	193.00	381.00	0.00
		II	631.00	110.00	135.00	147.00	198.00	0.00
		II	581.00	120.00	147.00	164.00	290.00	0.00
		II	399.00	74.00	90.00	88.00	234.00	0.00
FC	BT	II	693.00	152.00	218.00	212.00	206.00	0.00

Table C.4 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
		II	555.00	90.00	106.00	104.00	128.00	0.00
		II	501.00	76.00	101.00	138.00	83.00	189.00
		II	583.00	106.00	142.00	151.00	139.00	63.00
		II	583.00	106.00	142.00	151.00	139.00	63.00
	AT	II	674.00	131.00	182.00	223.00	94.00	0.00
		II	757.00	146.00	159.00	165.00	95.00	0.00
		II	841.00	146.00	192.00	200.00	113.00	0.00
		II	690.00	143.00	202.00	179.00	160.00	0.00
		II	735.00	143.00	189.00	184.00	183.00	0.00
D	BT	III	616.00	102.00	153.00	155.00	155.00	141.00
		III	709.00	107.00	150.00	150.00	62.00	0.00
		III	534.00	84.00	120.00	130.00	96.00	0.00
		III	620.00	98.00	141.00	145.00	104.00	47.00
		III	620.00	98.00	141.00	145.00	104.00	47.00
	AT	III	421.00	90.00	117.00	142.00	177.00	0.00
		III	422.00	109.00	168.00	220.00	339.00	0.00
		III	503.00	103.00	143.00	142.00	99.00	0.00
		III	306.00	89.00	151.00	175.00	100.00	0.00
		III	618.00	122.00	171.00	212.00	134.00	0.00
FC	BT	III	646.00	91.00	137.00	167.00	236.00	0.00
		III	594.00	75.00	96.00	95.00	42.00	171.00
		III	540.00	93.00	124.00	144.00	85.00	0.00
		III	593.00	86.00	119.00	135.00	121.00	57.00
		III	593.00	86.00	119.00	135.00	121.00	57.00
	AT	III	485.00	88.00	127.00	192.00	130.00	200.00
		III	627.00	88.00	104.00	104.00	33.00	0.00
		III	809.00	141.00	174.00	163.00	64.00	0.00
		III	760.00	95.00	120.00	111.00	120.00	0.00
		III	756.00	131.00	160.00	157.00	223.00	0.00
D	BT	IV	468.00	79.00	100.00	101.00	11.00	0.00
		IV	824.00	101.00	131.00	138.00	82.00	0.00
		IV	424.00	68.00	85.00	86.00	83.00	0.00
		IV	572.00	83.00	105.00	108.00	59.00	0.00
		IV	572.00	83.00	105.00	108.00	59.00	0.00
	AT	IV	407.00	900.00	116.00	135.00	84.00	0.00
		IV	603.00	125.00	166.00	224.00	183.00	0.00
		IV	357.00	76.00	116.00	117.00	122.00	168.00
		IV	636.00	132.00	162.00	242.00	96.00	0.00
		IV	503.00	119.00	185.00	197.00	296.00	0.00
FC	BT	IV	427.00	68.00	96.00	135.00	122.00	0.00
		IV	419.00	66.00	92.00	133.00	163.00	0.00
		IV	857.00	121.00	138.00	147.00	114.00	0.00

Table C.4 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
			....	....	....	gm	....	....
		IV	568.00	85.00	109.00	138.00	133.00	0.00
		IV	568.00	85.00	109.00	138.00	133.00	0.00
	AT	IV	522.00	129.00	181.00	205.00	173.00	0.00
		IV	592.00	87.00	109.00	174.00	117.00	0.00
		IV	518.00	113.00	157.00	218.00	261.00	0.00
		IV	762.00	105.00	111.00	108.00	66.00	202.00
		IV	805.00	128.00	155.00	132.00	109.00	0.00
Date: October 30, 1989								
Moisture content: 20.95 %								
FC	BT	I	751.00	153.00	231.00	323.00	246.00	0.00
		I	731.00	147.00	212.00	287.00	383.00	0.00
		I	601.00	124.00	199.00	243.00	238.00	0.00
		I	443.00	86.00	140.00	201.00	215.00	0.00
		I	964.00	209.00	282.00	338.00	147.00	0.00
	AT	I	620.00	139.00	165.00	194.00	92.00	0.00
		I	652.00	117.00	154.00	188.00	118.00	0.00
		I	373.00	95.00	132.00	158.00	206.00	251.00
		I	447.00	103.00	175.00	210.00	366.00	0.00
		I	550.00	135.00	158.00	156.00	102.00	145.00
D	BT	I	793.00	164.00	231.00	263.00	381.00	0.00
		I	820.00	174.00	235.00	318.00	212.00	11.00
		I	614.00	121.00	177.00	267.00	48.00	0.00
		I	833.00	153.00	238.00	238.00	224.00	0.00
		I	755.00	171.00	256.00	345.00	362.00	108.00
	AT	I	489.00	158.00	265.00	269.00	579.00	0.00
		I	612.00	212.00	302.00	351.00	520.00	0.00
		I	230.00	97.00	174.00	281.00	467.00	0.00
		I	648.00	176.00	238.00	275.00	238.00	0.00
		I	619.00	142.00	193.00	235.00	317.00	0.00
D	BT	II	524.00	136.00	231.00	294.00	336.00	0.00
		II	272.00	94.00	160.00	248.00	336.00	0.00
		II	449.00	118.00	204.00	251.00	106.00	0.00
		II	576.00	142.00	227.00	265.00	253.00	0.00
		II	632.00	126.00	187.00	179.00	102.00	0.00
	AT	II	482.00	150.00	214.00	299.00	355.00	265.00
		II	648.00	231.00	284.00	343.00	444.00	113.00
		II	556.00	187.00	286.00	406.00	410.00	247.00

Table C.4 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
		II	665.00	206.00	274.00	323.00	520.00	0.00
		II	368.00	126.00	196.00	247.00	449.00	1069.00
FC	BT	II	707.00	120.00	178.00	181.00	189.00	0.00
		II	566.00	114.00	153.00	232.00	294.00	0.00
		II	492.00	107.00	147.00	202.00	537.00	0.00
		II	592.00	103.00	155.00	246.00	223.00	0.00
		II	819.00	146.00	204.00	232.00	228.00	0.00
	AT	II	357.00	117.00	191.00	272.00	307.00	0.00
		II	384.00	127.00	212.00	265.00	361.00	74.00
		II	197.00	84.00	148.00	226.00	322.00	0.00
		II	383.00	127.00	194.00	201.00	523.00	437.00
		II	797.00	141.00	197.00	181.00	343.00	0.00
D	BT	III	616.00	117.00	156.00	146.00	28.00	0.00
		III	533.00	138.00	225.00	281.00	294.00	0.00
		III	526.00	115.00	173.00	185.00	227.00	0.00
		III	387.00	81.00	217.00	159.00	93.00	0.00
		III	814.00	115.00	179.00	61.00	44.00	0.00
	AT	III	411.00	128.00	199.00	206.00	448.00	0.00
		III	509.00	150.00	215.00	234.00	420.00	93.00
		III	616.00	171.00	277.00	280.00	223.00	234.00
		III	473.00	151.00	224.00	313.00	320.00	197.00
		III	615.00	153.00	196.00	252.00	173.00	109.00
FC	BT	III	632.00	98.00	100.00	119.00	17.00	0.00
		III	1104.00	121.00	169.00	162.00	102.00	0.00
		III	762.00	154.00	179.00	147.00	33.00	0.00
		III	768.00	149.00	138.00	106.00	7.00	0.00
		III	586.00	126.00	170.00	213.00	161.00	0.00
	AT	III	566.00	143.00	152.00	259.00	317.00	0.00
		III	644.00	149.00	208.00	251.00	355.00	0.00
		III	522.00	125.00	172.00	223.00	300.00	0.00
		III	428.00	114.00	179.00	210.00	211.00	0.00
		III	818.00	158.00	200.00	237.00	127.00	165.00
D	BT	IV	746.00	144.00	198.00	203.00	169.00	0.00
		IV	707.00	136.00	206.00	287.00	214.00	0.00
		IV	679.00	118.00	166.00	161.00	169.00	0.00
		IV	626.00	137.00	197.00	217.00	183.00	0.00
		IV	610.00	112.00	138.00	151.00	131.00	0.00
	AT	IV	118.00	208.00	274.00	238.00	455.00	293.00
		IV	503.00	139.00	185.00	243.00	309.00	933.00
		IV	484.00	153.00	214.00	254.00	296.00	0.00
		IV	537.00	154.00	275.00	199.00	223.00	355.00
		IV	377.00	159.00	239.00	286.00	777.00	0.00

Table C.4 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
			....	....	....	gm	....	....
FC	BT	IV	806.00	175.00	182.00	183.00	71.00	0.00
		IV	420.00	89.00	141.00	134.00	153.00	0.00
		IV	509.00	111.00	144.00	150.00	32.00	0.00
		IV	578.00	125.00	156.00	156.00	85.00	0.00
		IV	578.00	125.00	156.00	156.00	85.00	0.00
	AT	IV	651.00	151.00	183.00	226.00	196.00	0.00
		IV	877.00	197.00	271.00	259.00	225.00	0.00
		IV	757.00	125.00	136.00	113.00	45.00	0.00
		IV	991.00	226.00	287.00	266.00	149.00	0.00
		IV	753.00	136.00	194.00	225.00	45.00	0.00

Table C.5. Weight of size fractions of samples after dropping

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3

Date: August 29, 1989
Moisture content: 12.80 %

					gm			
FC	BT	I	972.0	124.0	118.0	89.0	45.0	0.00
		I	1097.0	148.0	156.0	120.0	105.0	0.00
		I	805.0	99.0	118.0	125.0	400.0	0.00
		I	929.0	99.0	127.0	105.0	86.0	0.00
		I	1275.0	107.0	92.0	38.0	3.0	0.00
	AT	I	1238.0	140.0	141.0	106.0	72.0	0.00
		I	1141.0	148.0	173.0	163.0	54.0	0.00
		I	953.0	130.0	164.0	136.0	83.0	153.00
		I	1010.0	181.0	222.0	234.0	244.0	0.00
		I	768.0	117.0	131.0	110.0	145.0	200.00
D	BT	I	894.0	118.0	128.0	127.0	162.0	0.00
		I	766.0	100.0	118.0	93.0	114.0	240.00
		I	647.0	108.0	165.0	216.0	297.0	0.00
		I	892.0	151.0	236.0	233.0	99.0	0.00
		I	1010.0	139.0	132.0	47.0	17.0	0.00
	AT	I	826.0	138.0	200.0	234.0	281.0	0.00
		I	765.0	144.0	191.0	185.0	92.0	0.00
		I	993.0	182.0	189.0	181.0	72.0	0.00
		I	811.0	169.0	197.0	204.0	217.0	0.00
		I	841.0	154.0	196.0	174.0	170.0	0.00
D	BT	II	793.0	112.0	164.0	200.0	180.0	0.00
		II	1122.0	132.0	162.0	165.0	214.0	0.00
		II	1105.0	129.0	134.0	164.0	88.0	0.00
		II	776.0	101.0	170.0	179.0	156.0	175.00
		II	837.0	120.0	158.0	136.0	84.0	0.00
	AT	II	745.0	165.0	220.0	213.0	241.0	0.00
		II	565.0	121.0	149.0	158.0	15.0	0.00
		II	812.0	146.0	146.0	137.0	232.0	0.00
		II	572.0	111.0	156.0	174.0	298.0	138.00
		II	590.0	130.0	192.0	191.0	174.0	245.00
FC	BT	II	1110.0	131.0	149.0	150.0	15.0	0.00
		II	1300.0	145.0	155.0	111.0	19.0	0.00
		II	1019.0	129.0	144.0	146.0	113.0	0.00
		II	1120.0	122.0	122.0	108.0	53.0	0.00
		II	1122.0	140.0	144.0	84.0	172.0	0.00
	AT	II	928.0	121.0	150.0	106.0	65.0	161.00
		II	1240.0	125.0	130.0	78.0	8.0	0.00

Table C.5 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
		II	1124.0	111.0	100.0	50.0	4.0	0.00
		II	1102.0	114.0	86.0	69.0	4.0	0.00
		II	1053.0	94.0	96.0	83.0	47.0	0.00
D	BT	III	927.0	124.0	148.0	104.0	176.0	183.00
		III	725.0	82.0	97.0	84.0	137.0	129.00
		III	1195.0	161.0	179.0	128.0	102.0	0.00
		III	956.0	99.0	93.0	75.0	3.0	0.00
	AT	III	899.0	121.0	136.0	110.0	124.0	0.00
		III	706.0	143.0	186.0	212.0	347.0	0.00
		III	427.0	91.0	122.0	132.0	318.0	136.00
		III	397.0	101.0	165.0	210.0	204.0	129.00
		III	493.0	95.0	111.0	146.0	107.0	0.00
FC	BT	III	742.0	124.0	172.0	170.0	230.0	151.00
		III	1175.0	167.0	182.0	103.0	86.0	0.00
		III	776.0	121.0	163.0	210.0	180.0	0.00
		III	845.0	133.0	171.0	184.0	203.0	0.00
		III	776.0	152.0	215.0	249.0	357.0	0.00
	AT	III	693.0	84.0	96.0	105.0	13.0	154.00
		III	817.0	127.0	157.0	159.0	173.0	0.00
		III	850.0	122.0	160.0	137.0	88.0	0.00
		III	796.0	119.0	142.0	215.0	397.0	0.00
		III	877.0	128.0	163.0	121.0	83.0	0.00
D	BT	IV	1134.0	116.0	136.0	141.0	103.0	0.00
		IV	1134.0	125.0	138.0	113.0	16.0	0.00
		IV	1221.0	131.0	129.0	139.0	64.0	0.00
		IV	1040.0	115.0	124.0	86.0	28.0	0.00
		IV	1147.0	135.0	124.0	97.0	59.0	0.00
	AT	IV	966.0	157.0	199.0	194.0	118.0	0.00
		IV	599.0	94.0	107.0	116.0	194.0	0.00
		IV	933.0	121.0	142.0	148.0	104.0	0.00
		IV	801.0	120.0	152.0	126.0	139.0	0.00
		IV	809.0	118.0	136.0	141.0	167.0	0.00
FC	BT	IV	1064.0	113.0	113.0	73.0	41.0	0.00
		IV	842.0	172.0	64.0	52.0	17.0	0.00
		IV	1165.0	147.0	172.0	128.0	13.0	0.00
		IV	1133.0	136.0	140.0	128.0	14.0	0.00
		IV	1283.0	129.0	129.0	85.0	59.0	0.00
	AT	IV	1215.0	117.0	114.0	94.0	216.0	0.00
		IV	1088.0	164.0	191.0	213.0	47.0	0.00
		IV	828.0	105.0	120.0	99.0	19.0	0.00
		IV	1027.0	107.0	113.0	97.0	26.0	0.00
		IV	1227.0	132.0	119.0	57.0	27.0	0.00

Table C.5. Weight of size fractions of samples after dropping

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
Date: August 22, 1989								
Moisture content: 13.46 %								
			.... gm					
D	BT	I	889.0	77.0	73.0	56.0	28.0	0.00
		I	708.0	76.0	65.0	50.0	76.0	0.00
		I	998.0	120.0	154.0	194.0	78.0	0.00
		I	1206.0	109.0	92.0	53.0	15.0	0.00
		I	692.0	79.0	87.0	88.0	47.0	0.00
	AT	I	621.0	109.0	147.0	149.0	182.0	0.00
		I	459.0	97.0	135.0	208.0	322.0	0.00
		I	458.0	109.0	168.0	199.0	350.0	0.00
		I	608.0	110.0	148.0	195.0	190.0	0.00
		I	652.0	106.0	133.0	135.0	57.0	0.00
FC	BT	I	889.0	77.0	73.0	56.0	28.0	0.00
		I	708.0	76.0	65.0	50.0	76.0	0.00
		I	998.0	120.0	154.0	194.0	78.0	0.00
		I	1206.0	109.0	92.0	53.0	15.0	0.00
		I	692.0	79.0	87.0	88.0	47.0	0.00
	AT	I	666.0	91.0	92.0	104.0	83.0	0.00
		I	635.0	74.0	85.0	62.0	141.0	0.00
		I	924.0	88.0	78.0	83.0	80.0	0.00
		I	523.0	103.0	111.0	126.0	95.0	0.00
		I	1033.0	129.0	112.0	94.0	66.0	0.00
FC	BT	II	829.0	86.0	87.0	92.0	4.0	0.00
		II	786.0	79.0	76.0	88.0	48.0	0.00
		II	766.0	79.0	78.0	56.0	18.0	0.00
		II	759.0	84.0	85.0	57.0	66.0	0.00
		II	1029.0	79.0	55.0	20.0	30.0	0.00
	AT	II	760.0	93.0	91.0	55.0	42.0	0.00
		II	926.0	122.0	142.0	157.0	27.0	0.00
		II	713.0	115.0	167.0	131.0	113.0	0.00
		II	731.0	91.0	119.0	98.0	123.0	0.00
		II	604.0	110.0	153.0	132.0	63.0	0.00
D	BT	II	829.0	86.0	87.0	92.0	4.0	0.00
		II	786.0	79.0	76.0	88.0	48.0	0.00
		II	766.0	79.0	78.0	56.0	18.0	0.00
		II	759.0	84.0	85.0	57.0	66.0	0.00
		II	1029.0	79.0	55.0	20.0	30.0	0.00
	AT	II	407.0	87.0	120.0	185.0	247.0	137.00
		II	719.0	100.0	112.0	77.0	174.0	0.00
		II	584.0	114.0	156.0	191.0	306.0	0.00

Table C.5 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
		II	848.0	144.0	140.0	108.0	87.0	0.00
		II	631.0	115.0	169.0	184.0	286.0	0.00
D	BT	III	795.0	81.0	82.0	80.0	62.0	0.00
		III	815.0	87.0	92.0	67.0	136.0	0.00
		III	1298.0	119.0	117.0	81.0	13.0	0.00
		III	711.0	83.0	81.0	82.0	97.0	0.00
		III	850.0	122.0	164.0	114.0	95.0	0.00
	AT	III	512.0	117.0	170.0	186.0	139.0	0.00
		III	636.0	97.0	97.0	84.0	60.0	0.00
		III	761.0	126.0	157.0	148.0	164.0	0.00
		III	552.0	127.0	212.0	235.0	185.0	0.00
		III	772.0	120.0	133.0	128.0	46.0	0.00
FC	BT	III	795.0	81.0	82.0	80.0	62.0	0.00
		III	815.0	87.0	92.0	67.0	136.0	0.00
		III	1298.0	119.0	117.0	81.0	13.0	0.00
		III	711.0	83.0	81.0	82.0	97.0	0.00
		III	850.0	122.0	164.0	114.0	95.0	0.00
	AT	III	371.0	98.0	164.0	192.0	290.0	0.00
		III	589.0	128.0	183.0	227.0	177.0	0.00
		III	331.0	71.0	138.0	203.0	327.0	0.00
		III	566.0	86.0	132.0	168.0	123.0	0.00
		III	831.0	108.0	126.0	88.0	87.0	0.00
FC	BT	IV	795.0	80.0	86.0	83.0	15.0	0.00
		IV	606.0	95.0	110.0	102.0	61.0	0.00
		IV	816.0	83.0	88.0	93.0	84.0	0.00
		IV	663.0	91.0	109.0	113.0	108.0	0.00
		IV	810.0	112.0	106.0	97.0	25.0	0.00
	AT	IV	561.0	120.0	175.0	138.0	281.0	0.00
		IV	746.0	111.0	142.0	131.0	76.0	0.00
		IV	696.0	140.0	187.0	209.0	141.0	0.00
		IV	714.0	100.0	95.0	143.0	114.0	0.00
		IV	738.0	120.0	158.0	134.0	135.0	0.00
D	BT	IV	795.0	80.0	86.0	83.0	15.0	0.00
		IV	606.0	95.0	110.0	102.0	61.0	0.00
		IV	816.0	83.0	88.0	93.0	84.0	0.00
		IV	663.0	91.0	109.0	113.0	108.0	0.00
		IV	810.0	112.0	106.0	97.0	25.0	0.00
	AT	IV	377.0	90.0	152.0	199.0	220.0	0.00
		IV	646.0	107.0	133.0	204.0	133.0	0.00
		IV	470.0	123.0	187.0	140.0	240.0	0.00
		IV	468.0	92.0	148.0	171.0	137.0	0.00
		IV	490.0	103.0	155.0	179.0	183.0	0.00

Table C.5 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
Date: September 5, 1989								
Moisture content: 15.46 %								
D	BT	I	884.0	96.0	106.0	77.0	94.0	0.00
		I	743.0	97.0	120.0	115.0	103.0	0.00
		I	722.0	66.0	57.0	41.0	61.0	0.00
		I	783.0	86.0	94.0	78.0	86.0	0.00
		I	783.0	86.0	94.0	78.0	86.0	0.00
	AT	I	424.0	108.0	128.0	140.0	60.0	0.00
		I	591.0	95.0	103.0	93.0	224.0	0.00
		I	427.0	86.0	104.0	98.0	209.0	0.00
		I	613.0	76.0	69.0	28.0	137.0	0.00
		I	461.0	85.0	94.0	95.0	97.0	100.00
FC	BT	I	699.0	68.0	56.0	24.0	3.0	0.00
		I	806.0	95.0	122.0	122.0	20.0	0.00
		I	669.0	182.0	88.0	72.0	19.0	0.00
		I	725.0	115.0	89.0	73.0	14.0	0.00
		I	725.0	115.0	89.0	73.0	14.0	0.00
	AT	I	634.0	65.0	61.0	52.0	31.0	0.00
		I	599.0	64.0	76.0	49.0	30.0	0.00
		I	750.0	86.0	74.0	63.0	11.0	0.00
		I	673.0	89.0	90.0	50.0	2.0	0.00
		I	677.0	60.0	63.0	39.0	10.0	0.00
D	BT	II	928.0	95.0	112.0	99.0	39.0	0.00
		II	1021.0	100.0	133.0	125.0	32.0	0.00
		II	835.0	91.0	96.0	73.0	46.0	0.00
		II	928.0	95.0	114.0	99.0	39.0	0.00
		II	928.0	95.0	114.0	99.0	39.0	0.00
	AT	II	733.0	107.0	111.0	97.0	71.0	0.00
		II	506.0	104.0	146.0	165.0	86.0	0.00
		II	595.0	97.0	103.0	92.0	104.0	0.00
		II	843.0	138.0	159.0	161.0	45.0	0.00
		II	594.0	84.0	86.0	52.0	39.0	0.00
FC	BT	II	724.0	173.0	199.0	123.0	73.0	0.00
		II	588.0	74.0	83.0	53.0	32.0	0.00
		II	531.0	70.0	84.0	96.0	18.0	0.00
		II	614.0	106.0	122.0	91.0	41.0	0.00
		II	614.0	106.0	122.0	91.0	41.0	0.00
	AT	II	543.0	86.0	94.0	85.0	168.0	0.00
		II	612.0	83.0	82.0	79.0	123.0	0.00
		II	600.0	80.0	91.0	82.0	53.0	0.00
		II	567.0	97.0	112.0	146.0	67.0	0.00

Table C.5 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
			gm					
		II	538.0	90.0	124.0	132.0	128.0	0.00
D	BT	III	785.0	85.0	100.0	54.0	13.0	0.00
		III	584.0	64.0	64.0	47.0	9.0	0.00
		III	713.0	81.0	88.0	40.0	43.0	0.00
		III	694.0	77.0	84.0	47.0	22.0	0.00
		III	694.0	77.0	84.0	47.0	22.0	0.00
	AT	III	385.0	68.0	97.0	55.0	151.0	0.00
		III	439.0	91.0	137.0	133.0	189.0	0.00
		III	669.0	80.0	84.0	35.0	31.0	0.00
		III	490.0	84.0	111.0	100.0	162.0	0.00
		III	549.0	92.0	115.0	117.0	23.0	0.00
FC	BT	III	894.0	71.0	64.0	40.0	20.0	0.00
		III	499.0	46.0	43.0	29.0	2.0	0.00
		III	628.0	72.0	84.0	83.0	17.0	0.00
		III	674.0	63.0	64.0	51.0	13.0	0.00
		III	674.0	63.0	64.0	51.0	13.0	0.00
	AT	III	702.0	117.0	124.0	105.0	56.0	0.00
		III	520.0	61.0	74.0	84.0	33.0	0.00
		III	657.0	78.0	86.0	75.0	3.0	0.00
		III	650.0	90.0	401.0	99.0	45.0	0.00
		III	719.0	105.0	117.0	132.0	87.0	0.00
D	BT	IV	461.0	43.0	43.0	11.0	0.0	0.00
		IV	805.0	79.0	71.0	30.0	16.0	0.00
		IV	727.0	99.0	101.0	84.0	3.0	127.00
		IV	664.0	74.0	72.0	44.0	6.0	42.00
		IV	664.0	74.0	72.0	44.0	6.0	42.00
	AT	IV	522.0	76.0	85.0	70.0	22.0	0.00
		IV	804.0	113.0	115.0	93.0	64.0	0.00
		IV	532.0	91.0	109.0	116.0	126.0	0.00
		IV	523.0	69.0	81.0	114.0	124.0	0.00
		IV	514.0	98.0	113.0	97.0	88.0	0.00
FC	BT	IV	631.0	86.0	105.0	83.0	20.0	0.00
		IV	458.0	60.0	66.0	75.0	31.0	0.00
		IV	587.0	57.0	72.0	52.0	57.0	0.00
		IV	559.0	68.0	81.0	70.0	36.0	0.00
		IV	559.0	68.0	81.0	70.0	36.0	0.00
	AT	IV	617.0	92.0	112.0	93.0	62.0	0.00
		IV	696.0	90.0	90.0	74.0	65.0	0.00
		IV	750.0	105.0	99.0	68.0	3.0	0.00
		IV	772.0	79.0	70.0	55.0	92.0	0.00
		IV	645.0	84.0	78.0	81.0	102.0	0.00

Table C.5 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
Date: October 30, 1989								
Moisture content: 20.95 %								
FC	BT	I	746.0	109.0	118.0	6.0	130.0	0.00
		I	699.0	131.0	155.0	150.0	127.0	0.00
		I	727.0	116.0	156.0	193.0	109.0	0.00
		I	710.0	104.0	116.0	108.0	23.0	0.00
		I	792.0	135.0	164.0	114.0	109.0	0.00
	AT	I	775.0	108.0	106.0	48.0	48.0	0.00
		I	607.0	115.0	115.0	136.0	34.0	0.00
		I	680.0	126.0	164.0	132.0	10.0	0.00
		I	665.0	104.0	138.0	109.0	28.0	0.00
		I	689.0	145.0	178.0	116.0	112.0	0.00
D	BT	I	989.0	155.0	156.0	113.0	90.0	0.00
		I	807.0	150.0	183.0	149.0	161.0	0.00
		I	704.0	110.0	122.0	92.0	18.0	0.00
		I	659.0	105.0	108.0	83.0	12.0	0.00
		I	845.0	141.0	162.0	128.0	7.0	0.00
	AT	I	584.0	138.0	203.0	190.0	245.0	0.00
		I	542.0	128.0	191.0	248.0	214.0	155.00
		I	365.0	133.0	191.0	216.0	277.0	0.00
		I	624.0	127.0	145.0	161.0	108.0	0.00
		I	786.0	130.0	150.0	63.0	53.0	0.00
D	BT	II	825.0	129.0	149.0	136.0	104.0	0.00
		II	722.0	147.0	184.0	185.0	121.0	0.00
		II	572.0	124.0	156.0	196.0	82.0	0.00
		II	683.0	93.0	93.0	65.0	40.0	0.00
		II	623.0	82.0	76.0	54.0	11.0	0.00
	AT	II	508.0	125.0	152.0	214.0	423.0	0.00
		II	570.0	141.0	173.0	152.0	212.0	170.00
		II	596.0	139.0	197.0	173.0	37.0	1107.00
		II	637.0	161.0	168.0	145.0	259.0	0.00
		II	534.0	165.0	240.0	244.0	689.0	304.00
FC	BT	II	793.0	125.0	115.0	97.0	22.0	0.00
		II	743.0	136.0	173.0	137.0	165.0	0.00
		II	859.0	93.0	94.0	85.0	76.0	0.00
		II	688.0	94.0	96.0	69.0	3.0	0.00
		II	901.0	124.0	121.0	91.0	28.0	0.00
	AT	II	430.0	100.0	125.0	117.0	152.0	96.00
		II	410.0	102.0	151.0	158.0	268.0	9.00
		II	412.0	126.0	182.0	176.0	77.0	0.00
		II	535.0	118.0	152.0	112.0	353.0	114.00
		II	478.0	101.0	139.0	97.0	165.0	0.00

Table C.5 (Continued)

Implt. type	State	Block number	Sieve size (in)					
			0-1/8	1/8-1/4	1/4-1/2	1/2-1	1 - 2	2 - 3
D	BT	III	573.0	85.0	94.0	59.0	27.0	0.00
		III	729.0	129.0	144.0	118.0	12.0	0.00
		III	572.0	94.0	120.0	96.0	59.0	0.00
		III	514.0	81.0	104.0	81.0	42.0	0.00
		III	534.0	85.0	95.0	62.0	0.0	0.00
	AT	III	380.0	75.0	121.0	185.0	331.0	173.00
		III	551.0	108.0	139.0	116.0	113.0	132.00
		III	696.0	143.0	176.0	183.0	301.0	0.00
		III	640.0	143.0	186.0	198.0	229.0	0.00
		III	547.0	91.0	141.0	148.0	220.0	0.00
FC	BT	III	657.0	65.0	66.0	40.0	2.0	0.00
		III	698.0	80.0	80.0	48.0	15.0	0.00
		III	718.0	97.0	94.0	37.0	34.0	0.00
		III	551.0	103.0	119.0	84.0	61.0	0.00
		III	593.0	91.0	85.0	35.0	72.0	0.00
	AT	III	562.0	111.0	146.0	160.0	103.0	0.00
		III	537.0	103.0	129.0	128.0	148.0	0.00
		III	518.0	129.0	174.0	158.0	137.0	171.00
		III	446.0	101.0	128.0	96.0	176.0	0.00
		III	580.0	105.0	126.0	92.0	151.0	0.00
D	BT	IV	667.0	121.0	159.0	124.0	74.0	0.00
		IV	707.0	94.0	130.0	94.0	48.0	0.00
		IV	557.0	89.0	103.0	82.0	88.0	0.00
		IV	667.0	109.0	120.0	38.0	21.0	0.00
		IV	625.0	73.0	68.0	35.0	3.0	0.00
	AT	IV	1083.0	152.0	179.0	148.0	124.0	0.00
		IV	895.0	152.0	169.0	124.0	79.0	0.00
		IV	381.0	93.0	116.0	138.0	290.0	0.00
		IV	707.0	148.0	162.0	132.0	229.0	442.00
		IV	348.0	122.0	177.0	243.0	254.0	296.00
FC	BT	IV	605.0	86.0	92.0	44.0	39.0	0.00
		IV	517.0	91.0	95.0	100.0	50.0	0.00
		IV	609.0	89.0	96.0	33.0	3.0	0.00
		IV	758.0	134.0	163.0	128.0	5.0	0.00
		IV	859.0	115.0	120.0	77.0	5.0	0.00
	AT	IV	668.0	128.0	129.0	104.0	60.0	186.00
		IV	715.0	114.0	125.0	138.0	118.0	0.00
		IV	810.0	90.0	78.0	41.0	35.0	0.00
		IV	878.0	88.0	79.0	51.0	3.0	0.00
		IV	712.0	120.0	136.0	128.0	223.0	0.00

Table C.6. Maximum force and crushing energy data

Impl. type	State	Dropped or un-dropped	Block #	moisture content	Aggregates size (in) 0.25 - 0.5 Max.F	0.25 - 0.5 Eng.	0.5 - 1.0 Max.F	0.5 - 1.0 Eng.
				% w/w	N	J	N	J
FC	BT	UND	I	12.80	9.31	0.0218	23.96	0.0032
FC	BT	UND	I	13.24	29.71	0.0219	21.64	0.0318
FC	BT	UND	I	15.46	13.37	0.0110	22.68	0.0345
FC	BT	UND	I	20.95	13.95	0.0220	21.41	0.0316
FC	AT	UND	I	12.80	11.75	0.0942	30.22	0.0423
FC	AT	UND	I	13.24	35.62	0.0876	45.86	0.0409
FC	AT	UND	I	15.46	9.89	0.0182	51.31	0.1458
FC	AT	UND	I	20.95	26.12	0.0239	99.17	0.1086
D	BT	UND	I	12.80	19.94	0.0566	18.16	0.1196
D	BT	UND	I	13.24	35.43	0.0516	52.59	0.0710
D	BT	UND	I	15.46	14.38	0.0303	35.32	0.0604
D	BT	UND	I	20.95	30.72	0.0528	47.72	0.0656
D	AT	UND	I	12.80	17.51	0.0350	49.61	0.0635
D	AT	UND	I	13.24	14.03	0.0258	86.43	0.1101
D	AT	UND	I	15.46	9.74	0.0274	49.80	0.0820
D	AT	UND	I	20.95	8.50	0.0131	55.71	0.0695
FC	BT	UND	II	12.80	17.31	0.0319	22.41	0.0319
FC	BT	UND	II	13.24	16.96	0.0326	36.24	0.0635
FC	BT	UND	II	15.46	33.65	0.0467	29.17	0.0733
FC	BT	UND	II	20.95	34.23	0.0399	84.75	0.1299
FC	AT	UND	II	12.80	9.31	0.0058	21.87	0.0483
FC	AT	UND	II	13.24	18.01	0.0306	17.82	0.0445
FC	AT	UND	II	15.46	13.95	0.0183	54.32	0.0883
FC	AT	UND	II	20.95	22.29	0.0451	63.13	0.0907
D	BT	UND	II	12.80	21.48	0.0164	36.36	0.0806
D	BT	UND	II	13.24	18.47	0.0072	42.27	0.0792
D	BT	UND	II	15.46	13.14	0.0083	21.63	0.0545
D	BT	UND	II	20.95	11.17	0.0190	24.08	0.0559
D	AT	UND	II	12.80	17.08	0.0429	22.34	0.0475
D	AT	UND	II	13.24	11.05	0.0985	23.26	0.0608
D	AT	UND	II	15.46	13.37	0.0241	46.67	0.0775
D	AT	UND	II	20.95	11.98	0.0129	48.11	0.0632
FC	BT	UND	III	12.80	17.77	0.0106	40.00	0.0495
FC	BT	UND	III	13.24	22.87	0.0180	17.59	0.0672
FC	BT	UND	III	15.46	15.57	0.0328	32.19	0.0631
FC	BT	UND	III	20.95	21.25	0.0401	86.54	0.1123
FC	AT	UND	III	12.80	15.22	0.0164	34.97	0.0836
FC	AT	UND	III	13.24	18.24	0.0220	17.69	0.0395
FC	AT	UND	III	15.46	21.25	0.0170	72.06	0.3538
FC	AT	UND	III	20.95	21.48	0.0540	40.88	0.0546

Table C.6 (Continued)

Implt. type	State	Dropped or un-dropped	Block #	moisture contnet	Aggregates size (in)			
					0.25 - 0.5		0.5 - 1.0	
					Max.F	Eng.	Max.F	Eng.
				% w/w	N	J	N	J
D	BT	UND	III	12.80	11.40	0.0155	84.00	0.1126
D	BT	UND	III	13.24	17.08	0.0401	60.93	0.1021
D	BT	UND	III	15.46	19.28	0.0452	37.98	0.0724
D	BT	UND	III	20.95	19.74	0.0185	106.24	0.1486
D	AT	UND	III	12.80	14.53	0.0140	36.82	0.0625
D	AT	UND	III	13.24	10.70	0.0240	37.64	0.0844
D	AT	UND	III	15.46	9.55	0.0108	72.29	0.1090
D	AT	UND	III	20.95	22.76	0.0266	70.78	0.0887
FC	BT	UND	IV	12.80	25.19	0.0686	68.58	0.1074
FC	BT	UND	IV	13.24	12.10	0.0362	37.17	0.1519
FC	BT	UND	IV	15.46	18.82	0.0393	67.65	0.1193
FC	BT	UND	IV	20.95	16.73	0.0505	33.00	0.1146
FC	AT	UND	IV	12.80	13.72	0.0697	24.89	0.0506
FC	AT	UND	IV	13.24	11.40	0.0248	28.25	0.0647
FC	AT	UND	IV	15.46	18.12	0.0207	52.19	0.1154
FC	AT	UND	IV	20.95	12.10	0.0189	84.11	0.1157
D	BT	UND	IV	12.80	17.20	0.0234	69.51	0.1100
D	BT	UND	IV	13.24	19.51	0.0235	18.82	0.0453
D	BT	UND	IV	15.46	30.98	0.0364	90.02	0.1180
D	BT	UND	IV	20.95	21.83	0.0586	49.91	0.0690
D	AT	UND	IV	12.80	19.74	0.0464	49.34	0.1003
D	AT	UND	IV	13.24	16.15	0.0314	39.95	0.0826
D	AT	UND	IV	15.46	29.59	0.0433	25.81	0.0643
D	AT	UND	IV	20.95	26.93	0.0373	91.24	0.0836
FC	BT	DR	I	12.80	21.99	0.0196	21.09	0.0307
FC	BT	DR	I	13.24	20.60	0.0106	22.22	0.0400
FC	BT	DR	I	15.46	17.47	0.0160	32.65	0.0407
FC	BT	DR	I	20.95	36.13	0.0654	51.20	0.0719
FC	AT	DR	I	12.80	76.17	0.0044	32.65	0.0747
FC	AT	DR	I	13.24	72.69	0.0068	19.21	0.0352
FC	AT	DR	I	15.46	12.83	0.0091	43.90	0.0867
FC	AT	DR	I	20.95	14.11	0.0122	42.27	0.0525
D	BT	DR	I	12.80	17.01	0.0249	27.13	0.0370
D	BT	DR	I	13.24	23.38	0.0194	25.47	0.0286
D	BT	DR	I	15.46	15.73	0.0316	60.50	0.1970
D	BT	DR	I	20.95	56.07	0.0613	65.95	0.1578
D	AT	DR	I	12.80	13.45	0.0082	39.84	0.0642
D	AT	DR	I	13.24	22.03	0.0519	67.54	0.1563
D	AT	DR	I	15.46	11.60	0.0101	54.91	0.0661
D	AT	DR	I	20.95	57.58	0.0470	71.60	0.0893

Table C.6 (Continued)

Implt. type	State	Dropped or un-dropped	Block #	Moisture content	Aggregates size (in)			
					0.25 - 0.5		0.5 - 1.0	
					Max.F	Eng.	Max.F	Eng.
FC	BT	DR	II	12.80	21.08	0.0215	42.51	0.1675
FC	BT	DR	II	13.24	24.66	0.0277	27.68	0.0449
FC	BT	DR	II	15.46	26.17	0.0428	31.04	0.0616
FC	BT	DR	II	20.95	10.41	0.0069	35.10	0.0538
FC	AT	DR	II	12.80	5.65	0.0023	42.05	0.1566
FC	AT	DR	II	13.24	10.41	0.0049	68.83	0.1122
FC	AT	DR	II	15.46	13.19	0.0153	50.16	0.1407
FC	AT	DR	II	20.95	16.07	0.0093	45.78	0.0652
D	BT	DR	II	12.80	21.77	0.0385	72.42	0.0869
D	BT	DR	II	13.24	15.62	0.0125	24.90	0.0322
D	BT	DR	II	15.46	13.19	0.0121	22.23	0.0527
D	BT	DR	II	20.95	28.72	0.0677	30.92	0.0507
D	AT	DR	II	12.80	19.55	0.0277	45.99	0.0644
D	AT	DR	II	13.24	12.48	0.0189	36.24	0.0422
D	AT	DR	II	15.46	23.14	0.0212	31.02	0.1159
D	AT	DR	II	20.95	16.07	0.0093	56.64	0.1879
FC	BT	DR	III	12.80	30.71	0.0256	52.27	0.2054
FC	BT	DR	III	13.24	10.66	0.0726	33.73	0.0329
FC	BT	DR	III	15.46	11.82	0.0057	34.66	0.0321
FC	BT	DR	III	20.95	22.83	0.0056	57.49	0.1018
FC	AT	DR	III	12.80	26.31	0.0312	47.64	0.0591
FC	AT	DR	III	13.24	5.45	0.0107	31.87	0.0348
FC	AT	DR	III	15.46	18.89	0.0041	21.67	0.0555
FC	AT	DR	III	20.95	28.86	0.0745	38.36	0.0413
D	BT	DR	III	12.80	8.23	0.0019	52.16	0.0532
D	BT	DR	III	13.24	11.74	0.0093	42.77	0.0435
D	BT	DR	III	15.46	9.77	0.0076	82.29	0.0931
D	BT	DR	III	20.95	15.68	0.0285	22.14	0.0245
D	AT	DR	III	12.80	30.28	0.0373	75.78	0.2582
D	AT	DR	III	13.24	26.22	0.0454	24.95	0.0330
D	AT	DR	III	15.46	13.48	0.0135	85.91	0.1191
D	AT	DR	III	20.95	31.90	0.0407	86.03	0.0923
FC	BT	DR	IV	12.80	9.00	0.0066	22.40	0.0247
FC	BT	DR	IV	13.24	18.34	0.0240	27.62	0.0287
FC	BT	DR	IV	15.46	10.58	0.0105	18.69	0.0271
FC	BT	DR	IV	20.95	10.23	0.0127	17.53	0.0145
FC	AT	DR	IV	12.80	34.22	0.0524	22.18	0.0229
FC	AT	DR	IV	13.24	31.44	0.0259	19.27	0.0227
FC	AT	DR	IV	15.46	40.25	0.0461	16.95	0.0182
FC	AT	DR	IV	20.95	44.30	0.0492	36.89	0.0553
D	BT	DR	IV	12.80	8.26	0.0031	33.29	0.0495
D	BT	DR	IV	13.24	17.07	0.0184	39.09	0.0478

Table C.6 (Continued)

Implt. type	State	Dropped or un-dropped	Block	Moisture content	Aggregates size (in) 0.25 - 0.5 Max.F	0.25 - 0.5 Eng.	0.5 - 1.0 Max. F	0.5 - 1.0 Eng.
D	BT	DR	IV	15.46	20.89	0.0235	33.29	0.0529
D	BT	DR	IV	20.95	12.43	0.0101	52.65	0.1360
D	AT	DR	IV	12.80	12.51	0.0083	67.57	0.0820
D	AT	DR	IV	13.24	23.29	0.0508	63.16	0.0706
D	AT	DR	IV	15.46	31.29	0.0563	44.97	0.0581
D	AT	DR	IV	20.95	10.89	0.0059	82.28	0.0505

APPENDIX D: ANALYSIS OF VARIANCE TABLES

Table D.1. Analysis of variance for aggregate size distribution of samples before tillage

Source of variation	d.f	Anova SS	F Value	PR > F
Rep	3	0.128	0.92	0.459
MC	3	0.232	1.68	0.225 n.s.[a]
Rep*MC	9	0.615	1.48	0.258
IMP	1	0.023	0.50	0.492 n.s.
IMP*MC	3	0.198	1.44	0.281

[a]Not significant.

Table D.2. Analysis of variance for aggregate size distribution of samples after tillage

Source of variation	d.f	Anova SS	F Value	PR > F
Rep	3	0.258	0.67	0.584
MC	3	2.509	6.56	0.007**
Rep*MC	9	0.871	0.76	0.655 n.s.[a]
IMP	1	1.506	11.81	0.005**
IMP*MC	3	0.293	0.77	0.535

[a]Not significant.

**Significant at 0.05 level.

Table D.3. Analysis of variance for aggregate mechanical stability of samples taken before tillage

Source of variation	d.f	Anova SS	F Value	PR > F
Rep	3	0.056	1.20	0.353
MC	3	0.026	0.18	0.910n.s.[a]
Rep*MC	9	0.436	3.09	0.036
IMP	1	0.0001	0.01	0.934n.s.
IMP*MC	3	0.129	2.74	0.089

[a]Not significant.

Table D.4. Analysis of variance for aggregate mechanical stability of samples after tillage

Source of variation	d.f	Anova SS	F Value	PR > F
Rep	3	0.020	0.11	0.952
MC	3	0.406	4.06	0.044[a]
Rep*MC	9	0.300	0.56	0.809
IMP	1	0.119	1.98	0.184*
IMP*MC	3	0.088	0.49	0.698

[a]Significant at 5 %.

*Significant at 18 %.

Table D.5. Analysis of variance for maximum force to crush aggregates that passed through 12.7 mm (0.5 in) screen and were retained on 6.35 mm (0.25 in) screen

Source of variation	d.f	Anova SS	F Value	PR > F
Rep	3	989.38	2.73	0.054
MC	3	432.18	0.66	0.600n.s.[a]
Rep*MC	9	1974.41	1.82	0.089
State	1	77.35	0.71	0.416
State*MC	3	56.18	0.17	0.914
Rep*State*MC	12	1309.53	0.90	0.549
IMP	1	121.10	0.89	0.355n.s.
IMP*MC	3	225.75	0.55	0.651n.s.
IMP*State	1	105.45	0.78	0.387
IMP*State*MC	3	86.95	0.21	0.886
Rep*State*MC*IMP	24	3263.21	1.13	0.353

[a]Not significant.

Table D.6. Analysis of variance of energy required to crush aggregates that passed through 12.7 mm (0.5 in) screen and were retained on 6.35 mm (0.25 in) screen

Source of variation	d.f	Anova SS	F Value	PR > F
Rep	3	0.0012	0.81	0.495
MC	3	0.0015	1.83	0.212n.s.[a]
Rep*MC	9	0.0024	0.55	0.833
State	1	0.0001	0.25	0.629
State*MC	3	0.0011	0.79	0.533
Rep*State*MC	12	0.0055	0.93	0.522
IMP	1	0.000002	0.01	0.940n.s.
IMP*MC	3	0.0005	0.41	0.746
IMP*State	1	0.00003	0.09	0.770
IMP*State*MC	3	0.0022	1.99	0.142
Rep*IMP*State*MC	24	0.0089	0.75	0.770

[a]Not significant.

Table D.7. Analysis of variance for maximum force to crush aggregates that passed 25.4 mm (1 in) screen and were retained on 12.7 mm (0.5 in) screen

Source of variation	d.f	Anova SS	F Value	PR > F
Rep	3	2378.56	2.08	0.116
MC	3	6831.03	7.80	0.007**
Rep*MC	9	2627.93	0.77	0.648
State	1	1301.65	2.65	0.071
State*MC	3	1154.94	0.79	0.525
Rep*State*MC	12	5883.88	1.29	0.258
IMP	1	4144.14	11.16	0.003**
IMP*MC	3	208.24	0.18	0.904
IMP*State	1	92.07	0.25	0.623
IMP*State*MC	3	444.21	0.40	0.755
Rep*State*MC*IMP	24	8910.15	0.97	0.515
DOU	1	532.20	1.39	0.243
DOU*MC	3	1333.27	1.16	0.333
State*DOU	1	281.68	0.74	0.395
IMP*DOU	1	702.28	1.84	0.181
State*DOU*MC	3	642.16	0.56	0.643
IMP*DOU*MC	3	1144.39	1.00	0.401
IMP*State*DOU	1	622.60	1.63	0.208
IMP*State*DOU*MC	3	276.23	0.24	0.867

**Significant at 1 %.

Table D.8. Analysis of variance of the energy required to crush aggregates that passed 25.4 mm (1 in) screen and were retained on 12.7 mm (0.5 in) screen

Source of variation	d.f	Anova SS	F Value	PR > F
Rep	3	0.007	0.93	0.435
MC	3	0.014	2.95	0.091[a]
Rep*MC	9	0.014	0.61	0.786
State	1	0.003	1.83	0.201
State*MC	3	0.006	1.20	0.352
Rep*State*MC	12	0.022	0.68	0.762
IMP	1	0.003	1.56	0.224n.s.[b]
IMP*MC	3	0.002	0.34	0.795
IMP*State	1	0.00003	0.02	0.896
IMP*State*MC	3	0.013	2.22	0.112
Rep*State*IMP*MC	24	0.047	0.74	0.790
DOU	1	0.003	1.00	0.323
DOU*MC	3	0.010	1.29	0.288
State*DOU	1	0.001	0.22	0.639
IMP*DOU	1	0.004	1.62	0.210
State*DOU*MC	3	0.007	0.97	0.416
IMP*DOU*MC	3	0.018	2.32	0.087
IMP*State*DOU	1	0.005	1.75	0.193
IMP*State*DOU*MC	3	0.006	0.79	0.505

[a]Significant at 10 %.

[b]Not significant.